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THE INFLUENCE OF VENTING ON THE APOLLO EARTH PARKING ORBITS

BY
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THE INFLUENCE OF VENTING ON THE APOLLO EARTH PARKING ORBITS

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SUMMARY

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The results of an error analysis study of the planned Apollo ground tracking system during 3 earth parking orbits for launch azimuths 72°, 90°, and 108° is presented. The emphasis is placed not upon the effect of system errors but rather upon the influence of the uncertainties of venting on the RMS errors in position and velocity.

A comparison is made of the RMS errors in position and velocity with and without uncertainties due to venting. Because of the various tracking situations encountered during 3 parking orbits with the 3 different launch azimuths, the effect of venting may be evaluated both during periods of concentrated tracking and during periods of no tracking.

AUTHOR

CONTENTS

	Page
SUMMARY	iii
INTRODUCTION	1
Tracking Network	2
Orbital Information	4
Tracking Mode for One Station	4
Tracking Mode for the Network	6
Venting Model	6
Launch Azimuth 72°	7
Launch Azimuth 90°	8
Launch Azimuth 108°	8
CONCLUSION	9
ACKNOWLEDGMENT	10
REFERENCES	10
List of Illustrations	vi
List of Tables	vi

LIST OF ILLUSTRATIONS

Figure		Page
1	Station contact times-launch azimuth 72°	11
2	Station contact times-launch azimuth 90°	12
3	Station contact times-launch azimuth 108°	13
4A	Ground coverage, launch azimuth 72°, height 185 km	14
4B	Ground coverage, launch azimuth 90°, height 185 km	15
4C	Ground coverage, launch azimuth 108°, height 185 km	16
5	Acquisition mode of tracking	17
6	Tracking mode for the network	18
7-20	Errors in spacecraft position and velocity Apollo parking orbit, launch azimuth 72°, height 185 km	21-34
21-39	Errors in spacecraft position and velocity Apollo parking orbit, launch azimuth 90°, height 185 km	37-55
40-51	Errors in spacecraft position and velocity Apollo parking orbit, launch azimuth 108°, height 185 km	59-70

LIST OF TABLES

Table		
1	Tracking Station Information	3
2	Orbital Parameters	5

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INTRODUCTION

The purpose of this report is to present the results of an error analysis study of the planned Apollo ground tracking system for all possible earth parking orbits. The study was initiated as an Apollo Navigation Working Group error analysis project and emphasizes the effect of venting.

The possible earth parking orbits are defined as 100 nautical mile altitude circular orbits launched over Cape Kennedy with launch azimuths between 72° and 108°. This study uses, in particular, parking orbits with launch azimuths of 72°, 90°, and 108°. The RMS errors in the position and velocity of the spacecraft are presented for the time between 30 minutes and 4-1/2 hours after insertion (3 parking orbits). Tracking is done by 11-stations of the Manned Space Flight Network (MSFN). The study assumes that only 50% of the maximum possible tracking information is used so as to give an upper bound on the RMS errors.

A comparison is made of the RMS errors in position and velocity with and without uncertainties due to venting. The effect of venting is a cumulative one and grows during periods of no tracking. This can be seen especially during the third orbit of launch azimuth 108°. The venting, as can be seen, does not influence the errors too drastically when the tracking intervals are in the order of 4-5 minutes but does influence the errors in position and velocity when there are large intervals of no tracking, even though the maximum RMS velocity error usually does not go above 1 meter/second.

It should be emphasized that this report deals with the influence of the venting model on the RMS position and velocity errors. No consideration is given to bias errors in the instruments such as bias errors in the azimuth, elevation, range, and range rate measurements. A more comprehensive study of this subject will follow if necessary.

Tracking Network

The tracking network for this study consists of eight land based stations and three tracking ships with variable locations for different launch azimuths. This was assumed to be more or less arbitrary since there may be more stations actually tracking the spacecraft; the emphasis however is placed upon a minimum of available tracking stations. To provide greater tracking coverage, the Atlantic Ship and the Indian Ocean Ship have different locations for launch azimuth 108° than they do for launch azimuths 72° and 90°. Altogether seven of the stations in the network provide tracking information for launch azimuth 72° and ten stations provide tracking information for each of launch azimuths 90° and 108°. The variances of total location uncertainty of a tracking station are given high values so as to provide an upper bound on their actual values and to reflect somewhat the biases in the measurements themselves. The tracking station location information is given in Table 1.

Station coverage for launch azimuths 72°, 90°, and 108° are given in Figures 1, 2, and 3 respectively. Passes not included in this study, as explained below, are enclosed in brackets.

For a launch azimuth of 72°, this network provides tracking coverage 4 times during the first orbit, 5 times during the second orbit, and 6 times during the third orbit. Tracking coverage is considered to be a time of at least 2 minutes when tracking is possible. This excludes the coverage of the Atlantic Ship on the second and third orbits and the Pacific Ship on the third orbit because of sufficient coverage by land based stations, and Hawaii on the second orbit because of a pass of small duration.

For a launch azimuth of 90°, this network provides tracking coverage 5 times during the first orbit, 8 times during the second orbit, and 7 times during the third orbit. This excludes the coverage of the Atlantic Ship on the second orbit and the Pacific Ship on the second and third orbits.

For a launch azimuth of 108°, this network provides tracking coverage 7 times during the first orbit, 5 times during the second orbit, and 1 time during the third orbit. This excludes the coverage of the Pacific Ship on the second orbit and also Antigua and Guam on the first orbit and Hawaii on the third orbit because of passes of small duration.

The Unified S-Band System is assumed to provide the tracking data at each station. The 1-sigma standard deviations in the measurements are based upon the assumptions that the system is capable of range measurements with a probable accuracy of 15 meters, range rate measurements with a resolution of 0.1

Table 1

Tracking Station Information*

Launch Azimuth**			Station Name	Latitude	Longitude	Total Location Uncertainty (meters)
72°	90°	108°				
	X	X	Antigua	17° 08' 32".586 N	61° 41' 43".464 W	± 150
	X	X	Ascension	07° 58' 28".920 S	14° 23' 31".920 W	± 250
X	X		Atlantic Ship 1	26° 40' 00".000 N	49° 20' 00".000 W	± 450
		X	Atlantic Ship 2	24° 00' 00".000 N	49° 40' 00".000 W	± 450
X	X		Bermuda	32° 20' 51".100 N	64° 39' 12".800 W	± 150
X	X	X	Cape Kennedy	28° 28' 54".340 N	80° 34' 35".450 W	± 50
X	X	X	Carnarvon	24° 52' 00".000 S	113° 38' 00".000 E	± 500
	X	X	Guam	13° 37' 52".802 N	144° 51' 07".824 E	± 800
X	X	X	Guaymas	27° 57' 30".240 N	110° 43' 14".860 W	± 300
X	X	X	Hawaii	22° 07' 31".000 N	159° 40' 15".600 W	± 800
X	X		Indian Ocean Ship 1	26° 00' 00".000 S	64° 00' 00".000 E	±1414
		X	Indian Ocean Ship 2	26° 00' 00".000 S	60° 00' 00".000 E	±1414
		X	Pacific Ship 1	17° 00' 00.000 N	165° 00' 00".000 E	±1414

* Height above the reference ellipsoid was assumed to be 0.

* * Those stations that provide tracking information are denoted by X.

meters/second, and angular measurements (azimuth and elevation) with an accuracy of 6×10^{-4} radians. The data sampling rate is one measurement every second and the local elevation angle below which no measurements are made is 5 degrees.

It should also be noted that no particular antenna pattern, but rather omnidirectional coverage of the spacecraft, was assumed. If a restriction is made, the results presented here will have to be modified. However some allowance for future restrictions has been made by assuming only a 50% coverage for each station.

Orbital Information

The lunar missions will use a variable launch azimuth of 72° to 108° to provide a four-hour "launch window". In order to evaluate the tracking network for various parking orbits of 185 kilometers height, launch azimuths of 72°, 90°, and 108° were chosen for study. Three complete earth-parking orbits were used to cover the maximum time in parking orbit before insertion into lunar transfer orbit. The orbital parameters for the orbits chosen with launch azimuths of 72°, 90°, and 108° are given in Table 2.

Figures 4A, 4B, and 4C show the first and third orbits as well as the ground coverage of the tracking network for the parking orbits with launch azimuths 72°, 90°, and 108° respectively. Orbital counting starts at longitude 80° west.

Tracking Mode for One Station

Since an uncertain amount of time is needed for a tracking radar to acquire a spacecraft after it transits above the horizon of the tracking station, a simulation of the so-called "searching" or "acquisition" time was incorporated in all the analyses presented herein. The optimum tracking situation occurs when tracking is done during the entire tracking interval that the spacecraft is possibly visible to the tracker (tracking from horizon to horizon). This implies immediate acquisition by the radar. The worst tracking situation occurs when no tracking is done by the tracking radar. Between these situations are cases where a radar requires time to acquire the spacecraft before tracking can begin—thus the total tracking time by the radar is shortened from the maximum possible by the amount of the acquisition time.

The acquisition mode of tracking was simulated by varying the starting time of the tracking while keeping the end time of the tracking fixed. The tracking

Table 2

Orbital Parameters –
Epoch: Aug 5, 1961 $0^h\ 5^m\ 0\overset{s}{.}6$

	Launch Az. 72°	Launch Az. 90°	Launch Az. 108°
Semi-Major Axis (km)	6563.165	6563.165	6563.165
Eccentricity	0.00000712	0.00000712	0.00000712
Inclination (Degrees)	33.28519	28.48177	33.28521
Rt. Ascension of Ascending Node (Degrees)	178.2521	143.9837	109.7153
Argument of Perigee (Degrees)	83.63545	113.3208	142.9646
Mean Anomaly (Degrees)	0.0	0.0	0.0
x (km)	-893.525	-1013.448	-1343.422
y (km)	-5427.891	-5812.650	-6046.755
z (km)	3579.684	2874.117	2169.446
x (km/sec)	7.71955	7.38312	6.47910
y (km/sec)	-0.95809	-2.01474	-2.66440
z (km/sec)	0.47412	-1.47125	-3.41415

time henceforth refers to the time from the instant of first acquisition to the instant that the spacecraft is last visible over the tracking station. The errors are always evaluated at the fixed instant tracking ends. If no tracking occurs this is a prediction. Figure 5 shows a schematic diagram of the acquisition mode of tracking.

Tracking Mode for the Network

Tracking over any station must take account of any previously accumulated tracking information. However, since the acquisition time is variable for each station, the accumulated tracking information is likewise variable. To take account of this variable and other factors such as deviations in local station predictions from the nominal trajectory, malfunctions leading to erroneous data, antenna patterns, etc., only 50% of the maximum possible accumulated tracking information was assumed. This is a somewhat pessimistic assumption for most tracking situations and results in an upper bound on the probable errors in position and velocity of the spacecraft.

To simulate this mode of tracking, the tracking information from the last half of the maximum possible tracking intervals for each station, from station 1 to station N-1, is combined to give the a-priori information assumed at the first acquisition of the spacecraft by station N. Figure 6 shows a schematic diagram of the tracking mode for the network.

Venting Model

The RMS errors in position and velocity are increased because of an uncertainty in thrust due to venting during the three parking orbits. The venting model used contains the following assumptions (see reference 1):

a. the body axis of the vehicle is aligned with the instantaneous velocity vector
b. the venting thrust acts along the instantaneous velocity axis direction in a manner to increase the velocity
c. the acceleration due to venting is a constant.

The error model assumes an uncertainty in the direction of venting and an uncertainty in the magnitude of the thrust.

In this study the acceleration due to venting is taken as $.4 \times 10^{-6}$ kilometers/(second)^2. Then the incremental velocity added as a result of venting (for a short time interval Δt) is $(.4 \times 10^{-6})\Delta t$ kilometers/second. This results from a thrust of approximately 10 pounds in the direction opposite the velocity vector. A 50% uncertainty in magnitude of thrust is taken and the uncertainty in the direction of venting is taken to be .5 radians or approximately 28.5°. This model has been found to be approximately the same as one with 7 pounds of thrust, a 100% uncertainty in magnitude, and an uncertainty in direction of .5 radians which is the latest information available at this time.

Launch Azimuth 72°

Figures 7 to 20 show the RMS errors in position and velocity of the spacecraft for 3 parking orbits inserted with launch azimuth 72°, both with and without the effect of venting.

Thirty minutes after insertion into parking orbit (with tracking from the Atlantic Ship only) the RMS error in position is 4.1 kilometers and the RMS error in velocity is 4.1 meters/second. This assumes that there is no tracking during this time interval except by the ship at the beginning and the RMS errors, therefore, represent a projected error from the ship tracking to the end of 30 minutes. With each station taking 50% of its maximum possible tracking information, the RMS error in position is never greater than 850 meters thereafter to the end of the third parking orbit, except before tracking by Guaymas on the first and second orbits, and the RMS error in velocity is never greater than 1.0 meters/second thereafter to the end of the third parking orbit except before tracking by Guaymas on the first and second orbits and Hawaii on the third orbit.

The RMS error in position is lowest from the last observation of Guaymas on the first orbit to the last observation of Carnarvon on the second orbit (a period of approximately 55 minutes) and from the last observation of Guaymas on the second orbit to the last observation of the Indian Ocean Ship on the third orbit (a period of approximately 45 minutes); in these periods the RMS error in position is continually less than 500 meters. The RMS error in velocity is lowest from the last observation of Cape Kennedy to the last observation of Bermuda on the second and third orbits (approximately 4 minute periods); in these periods the RMS error in velocity is continually less than .3 meters/second. Please note that this is the influence of the venting model in essence and does not take into account the measurement bias errors. The RMS errors in position and velocity are highest before tracking by Guaymas on the first orbit (because of a 33 minute period of no tracking between Carnarvon and Guaymas), before tracking by Guaymas on the second orbit (because of a 32 minute period of no tracking between Carnarvon and Guaymas), and before tracking by Hawaii on the third orbit (because of a 20 minute period of no tracking between Carnarvon and Hawaii).

In most cases a gap in tracking coverage results in an increase in the RMS errors in position and velocity. When the RMS errors in position and velocity increase due to a gap in tracking coverage, a small amount of tracking information (30 seconds or less) can bring about a sharp decrease in the RMS errors. Examples of this are tracking by Ascension on the first orbit and Guam, Guaymas, and the Indian Ocean Ship on the third orbit.

Launch Azimuth 90°

Figures 21 to 39 show the RMS errors in position and velocity of the spacecraft for 3 parking orbits inserted with launch azimuth 90°, both with and without the effect of venting.

Thirty minutes after insertion into parking orbit (with tracking from the Atlantic Ship only) the projected RMS error in position is 1.7 kilometers. With each station taking 50% of its maximum possible tracking information, the error in position is never greater than 681 meters thereafter to the end of the third parking orbit. Beyond the first parking orbit the position error is never greater than 500 meters except before tracking by Hawaii on the second orbit and before tracking by Guam on the third parking orbit. Thirty minutes after insertion into parking orbit the projected RMS error in velocity is 1.8 meters/second. With each station taking 50% of its maximum possible tracking information, the error in velocity is never greater than 1.0 meters/second thereafter to the end of the third parking orbit except before tracking by Hawaii on the second orbit.

The RMS errors are lowest from the last observation of Guaymas to the last observation of Ascension on the second orbit (a period of approximately 26 minutes) and from the last observation of Guaymas to the last observation of Ascension on the third orbit (a period of approximately 25 minutes); the RMS error in position is continually less than 300 meters and the RMS error in velocity is continually less than .5 meters/second during these periods. After the first orbit the RMS errors in position and velocity are highest before tracking by Hawaii on the second orbit (because of a 20 minute period of no tracking between Carnarvon and Hawaii) and before tracking by Guam on the third orbit (because of an 18 minute period of no tracking between the Indian Ocean Ship and Guam). This does not take into account the measurement bias errors.

Launch Azimuth 108°

Figures 40 to 51 show the RMS errors in position and velocity of the spacecraft for 3 parking orbits inserted with launch azimuth 108°, both with and without the effect of venting.

Ten minutes after insertion into parking orbit (with tracking from the Atlantic Ship only) the projected RMS error in position is 2.0 kilometers. With each station taking 50% of its maximum possible tracking information, the RMS error in position is never greater than 1.0 kilometers thereafter for the first two orbits except before tracking by Guam on the second orbit. Ten minutes after insertion into parking orbit the projected RMS error in velocity is 3.2 meters/second. With each station taking 50% of its maximum possible tracking information, the error in velocity is never greater than 1.0 meters/second thereafter for the first two orbits except before tracking by both Guam and Guaymas on the second orbit.

The RMS error in position is lowest from the last observation of Ascension on the first parking orbit to the last observation of Antigua on the second parking orbit (a period of approximately 79 minutes); in this period the RMS error in position is continually less than 500 meters. The RMS error in velocity is lowest from the last observation of Guaymas on the first orbit to the last observation of Antigua on the second orbit (a period of approximately 12 minutes); in this period the RMS error in velocity is continually less than .5 meters/second. The RMS errors in position and velocity are highest on the second orbit before tracking by the Indian Ship (because of a 28 minute period of no tracking between Antigua and the Indian Ship), before tracking by Guam (because of a 19 minute period of no tracking between the Indian Ship and Guam), and before tracking by Guaymas (because of a 20 minute period of no tracking between Guam and Guaymas). The RMS errors in position and velocity increase considerably on the third orbit since only the Indian Ship provides tracking information. (There is a 40 minute period of no tracking between Guaymas and the Indian Ship and over a 45 minute period of no tracking between the Indian Ship and the end of the third parking orbit.) At the end of the third parking orbit the RMS error in position is 4.0 kilometers and the RMS error in velocity is 4.4 meters/second. This illustrates the effect of venting during periods of little or no tracking. Note that these figures do not take into account the measurement bias errors.

CONCLUSION

The RMS errors in position and velocity are increased because of an uncertainty in thrust due to venting during the three parking orbits. In general the effect of venting depends on the tracking coverage. For tracking intervals in the order of 4-5 minutes or for small gaps in the tracking, the influence of venting is small. However for large intervals of no tracking (especially over 20 minutes) the effect of venting is usually pronounced. Also the effect of venting is a cumulative one and results in sizeable increases in the RMS errors in position and velocity especially during the second and third parking orbits.

However the RMS error in position usually does not exceed 1 kilometer and the RMS error in velocity usually does not exceed 1 meter/second. Note that the actual errors may however be larger as no consideration was given in this study to any bias errors in the measurements themselves.

ACKNOWLEDGMENT

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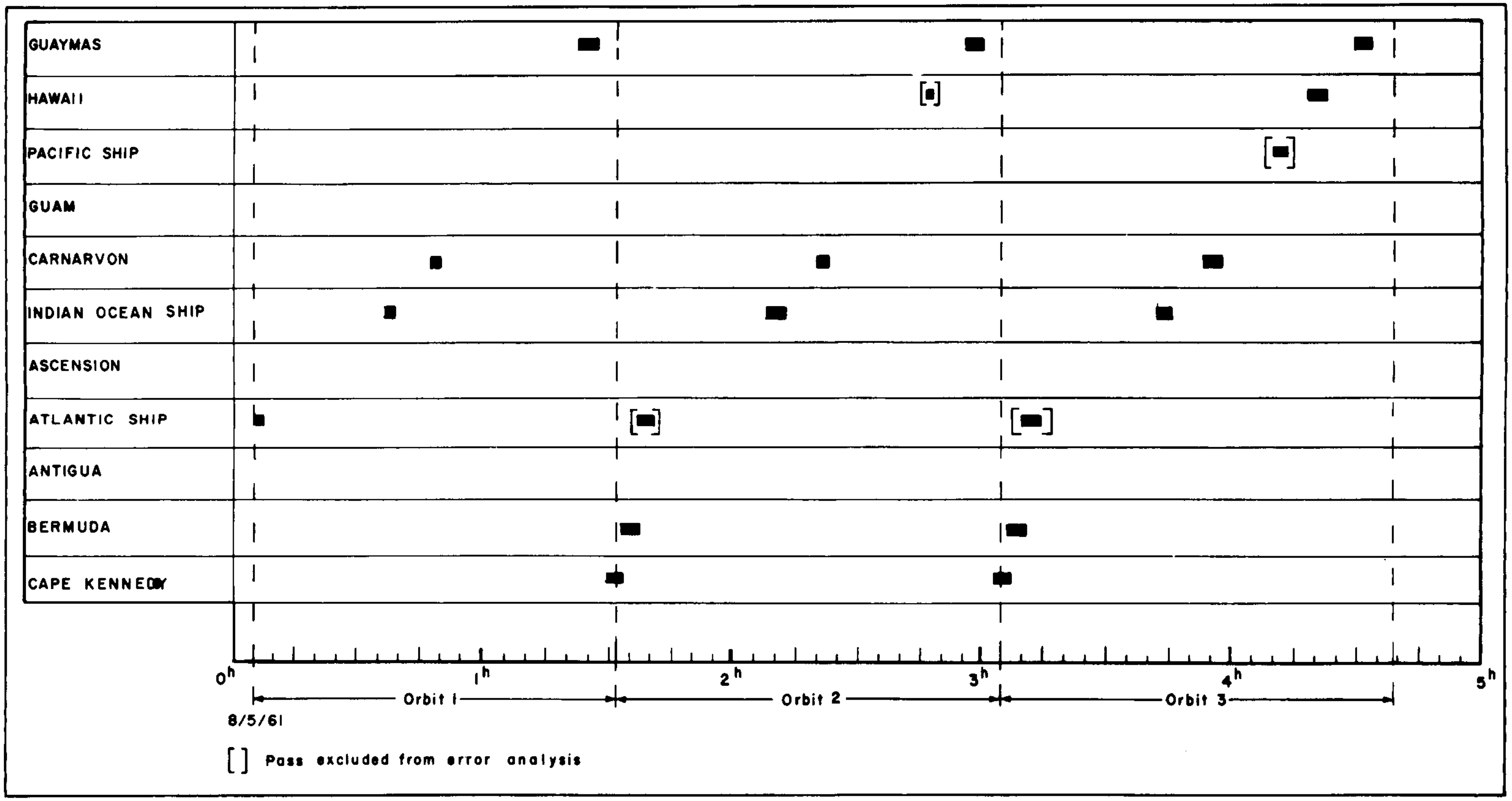

Figure 1—Station contact times-launch azimuth 72°.

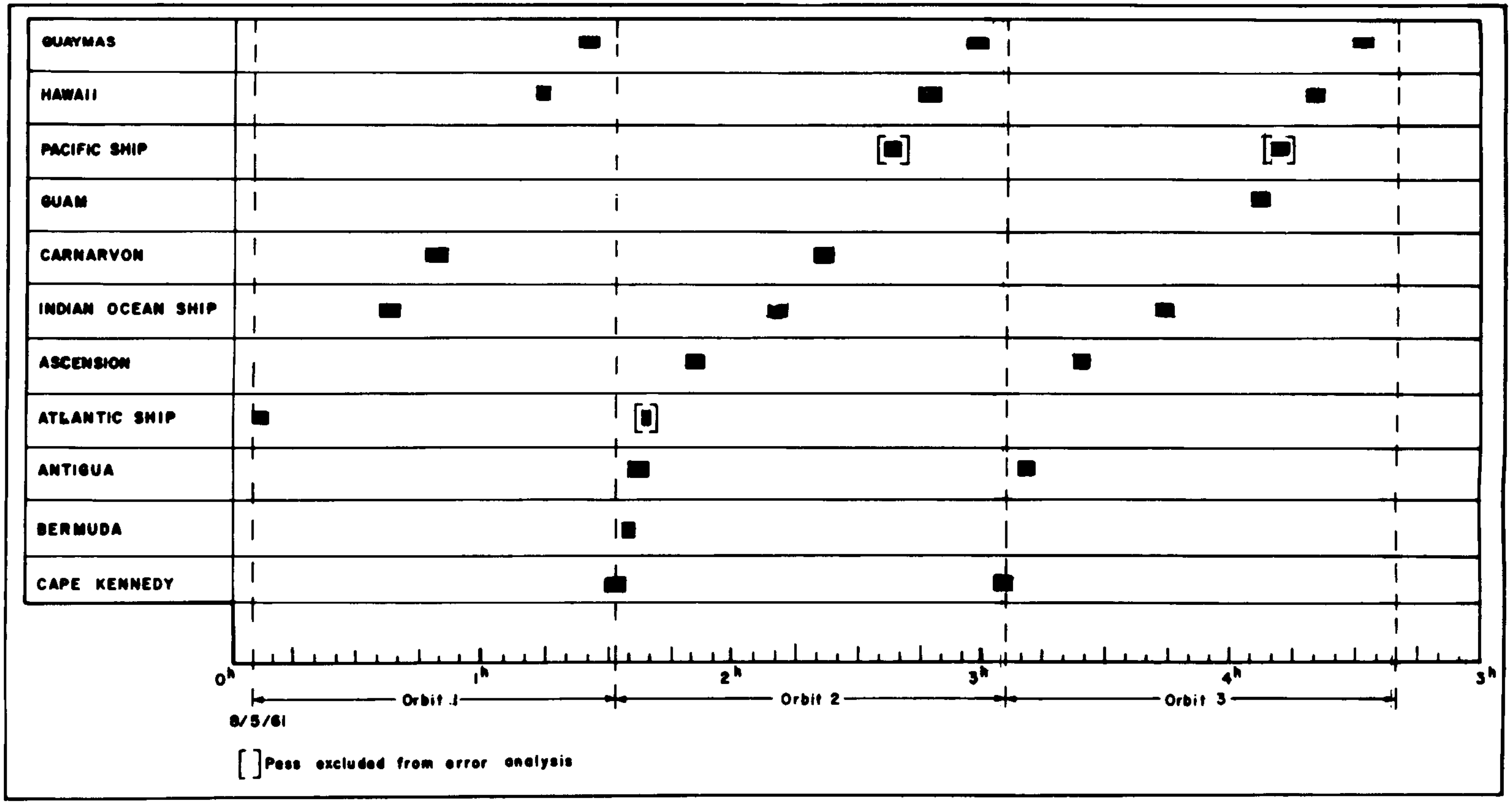

Figure 2—Station contact times-launch azimuth 90°.

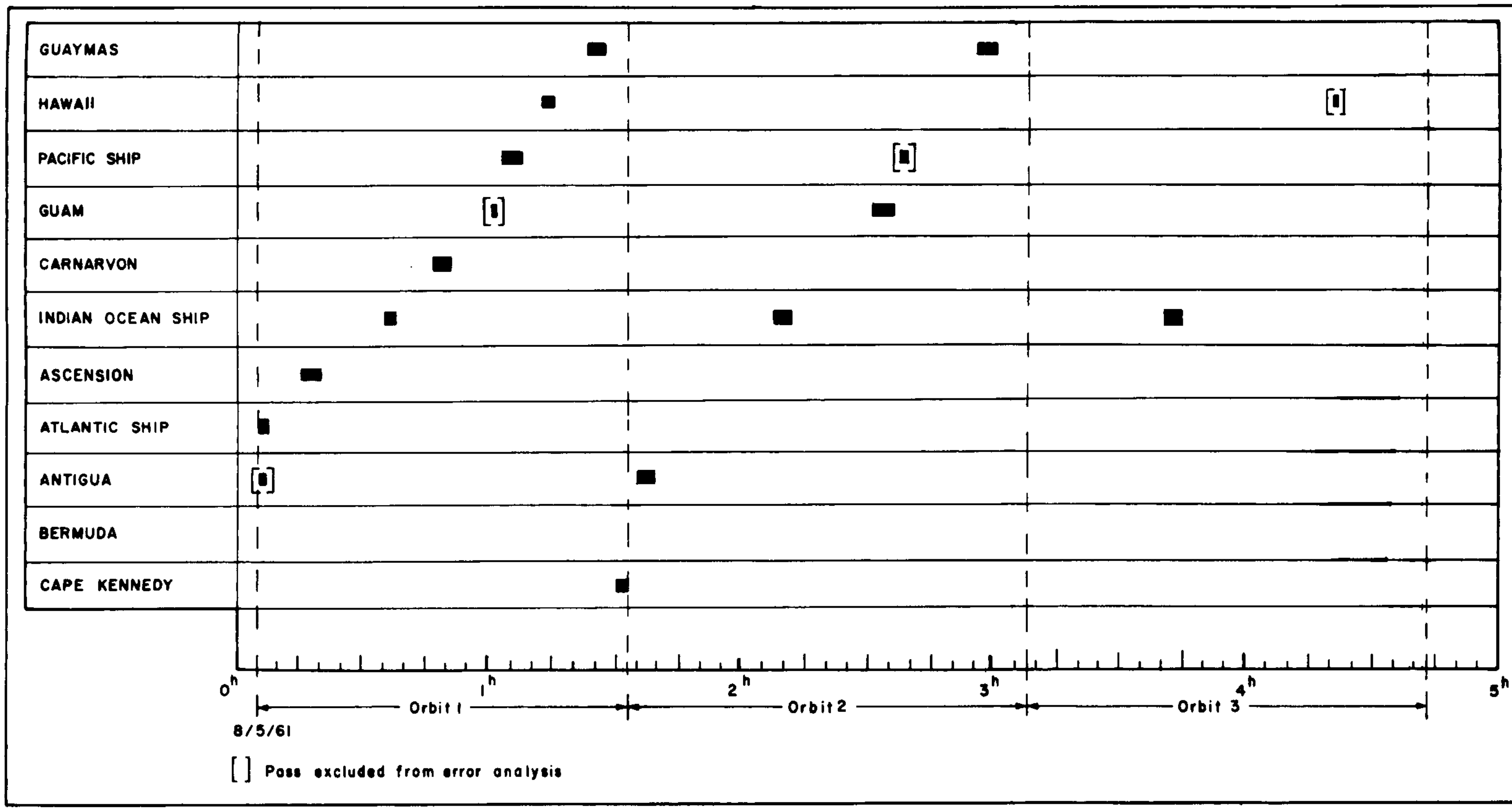

Figure 3—Station contact times-launch azimuth 108°.

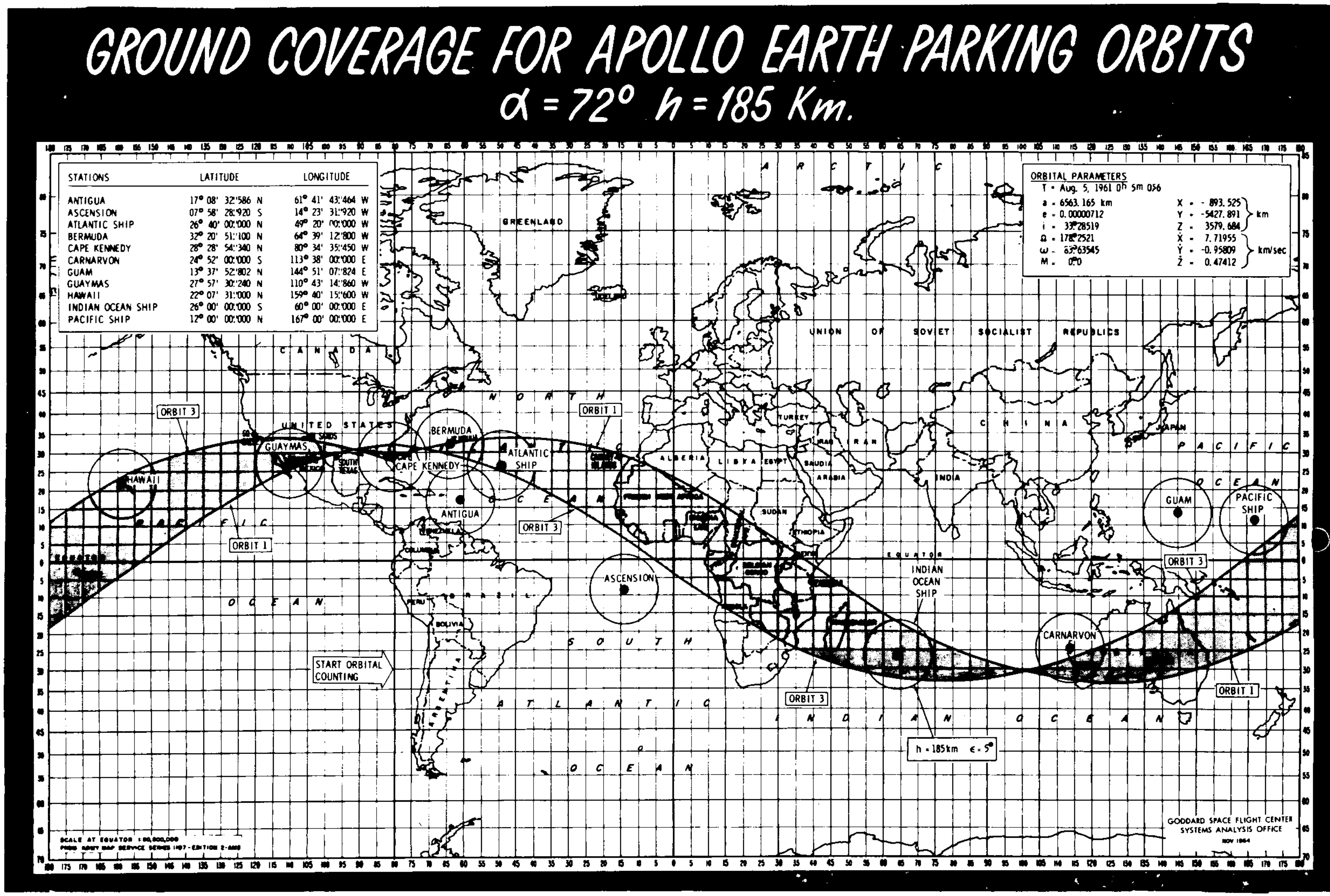

Figure 4A—Ground coverage, launch azimuth 72°, height 185 km.

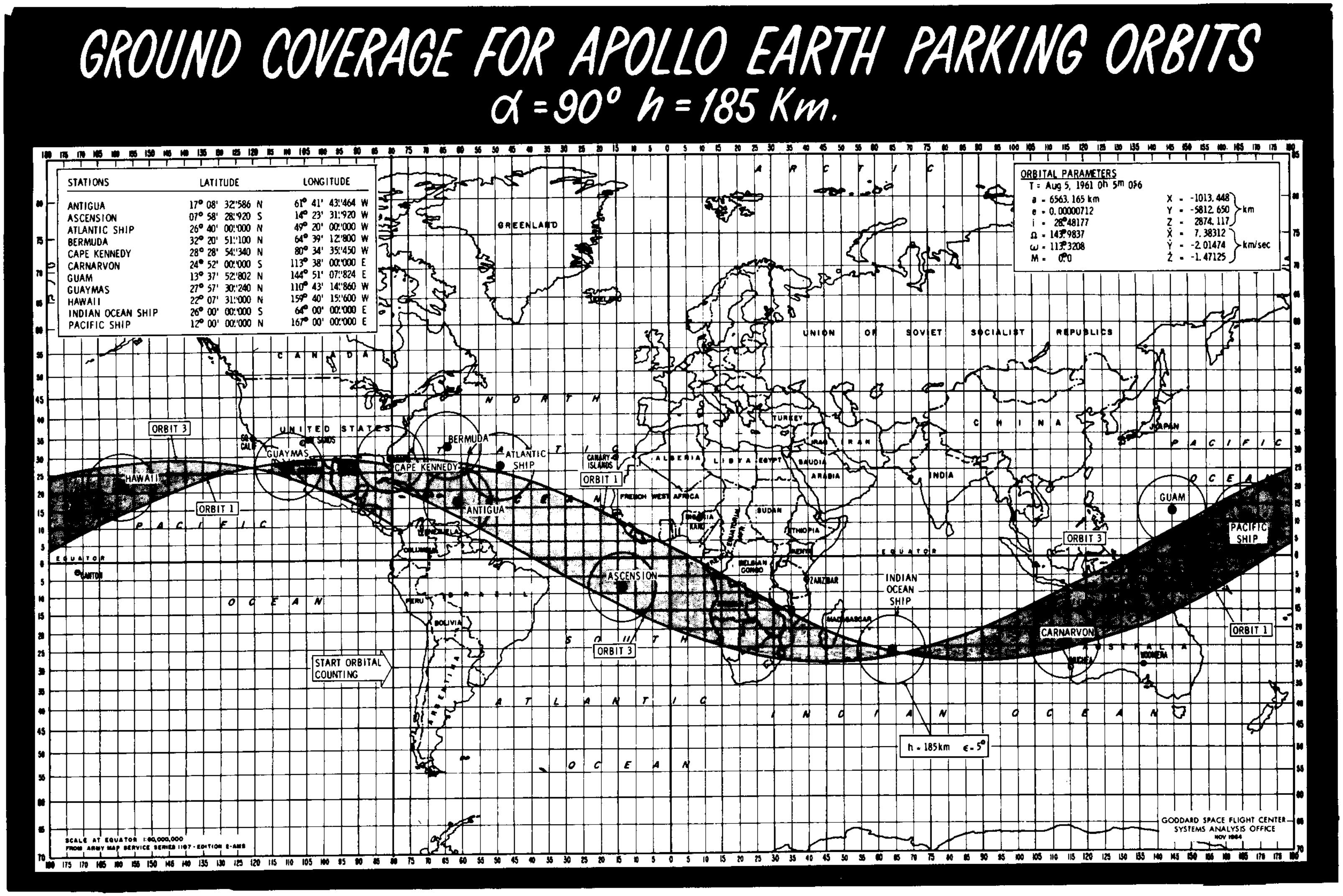

Figure 4B—Ground coverage, launch azimuth 90°, height 185 km.

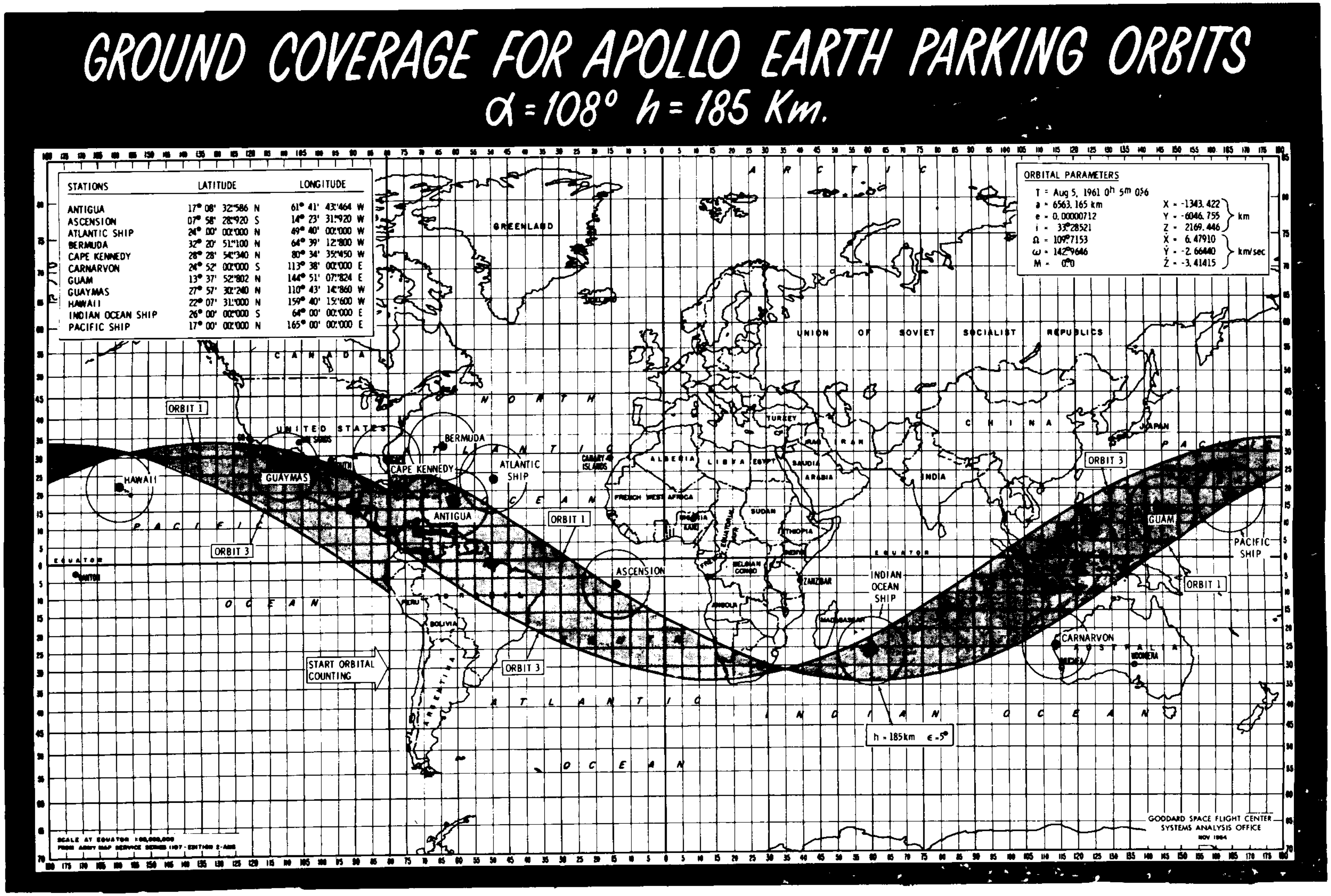

Figure 4C—Ground coverage, launch azimuth 108°, height 185 km.

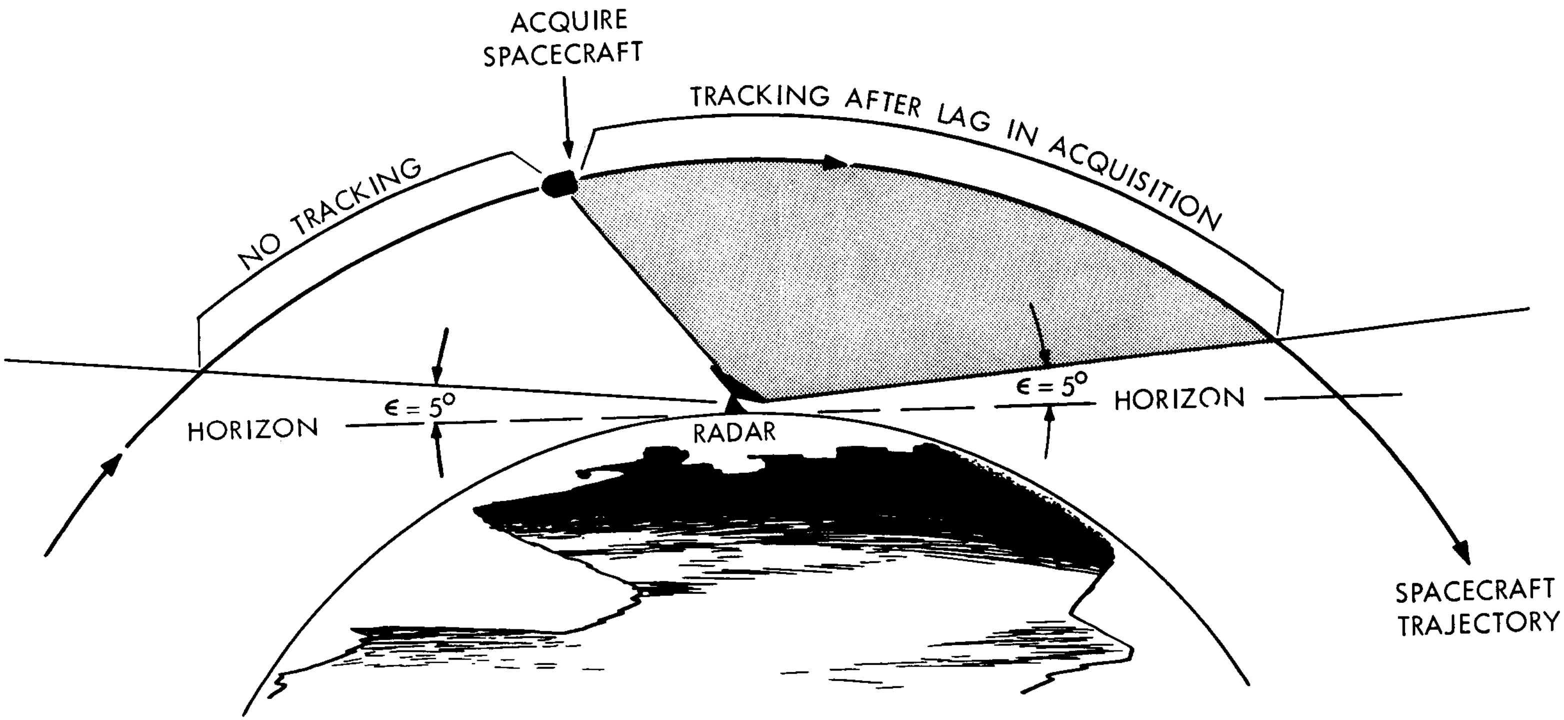

Figure 5—Acquisition mode of tracking.

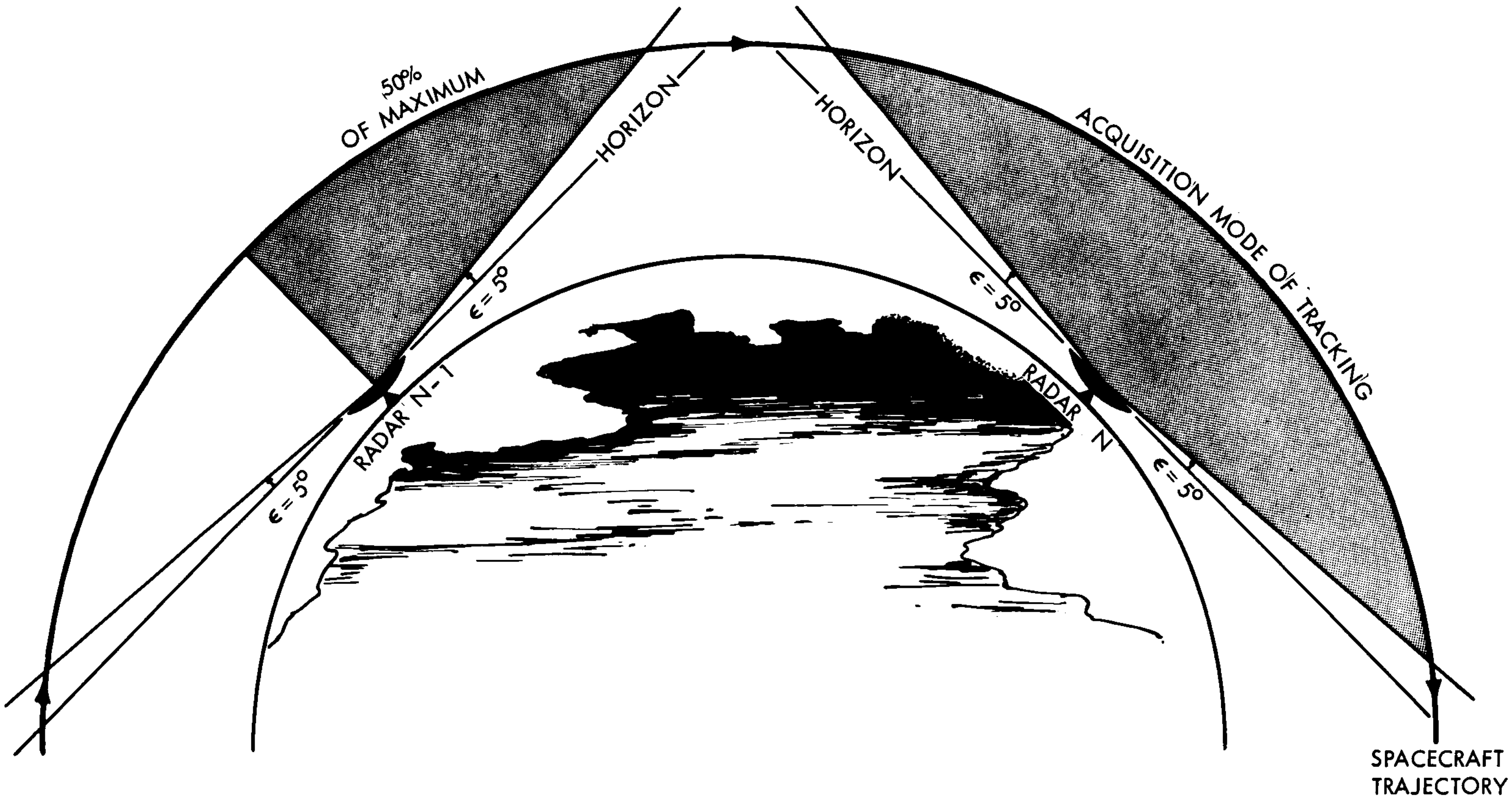

Figure 6—Tracking mode for the network.

FIGURES 7-20

ERRORS IN SPACECRAFT POSITION AND VELOCITY

APOLLO PARKING ORBIT, LAUNCH AZIMUTH 72°, HEIGHT 185 KM.

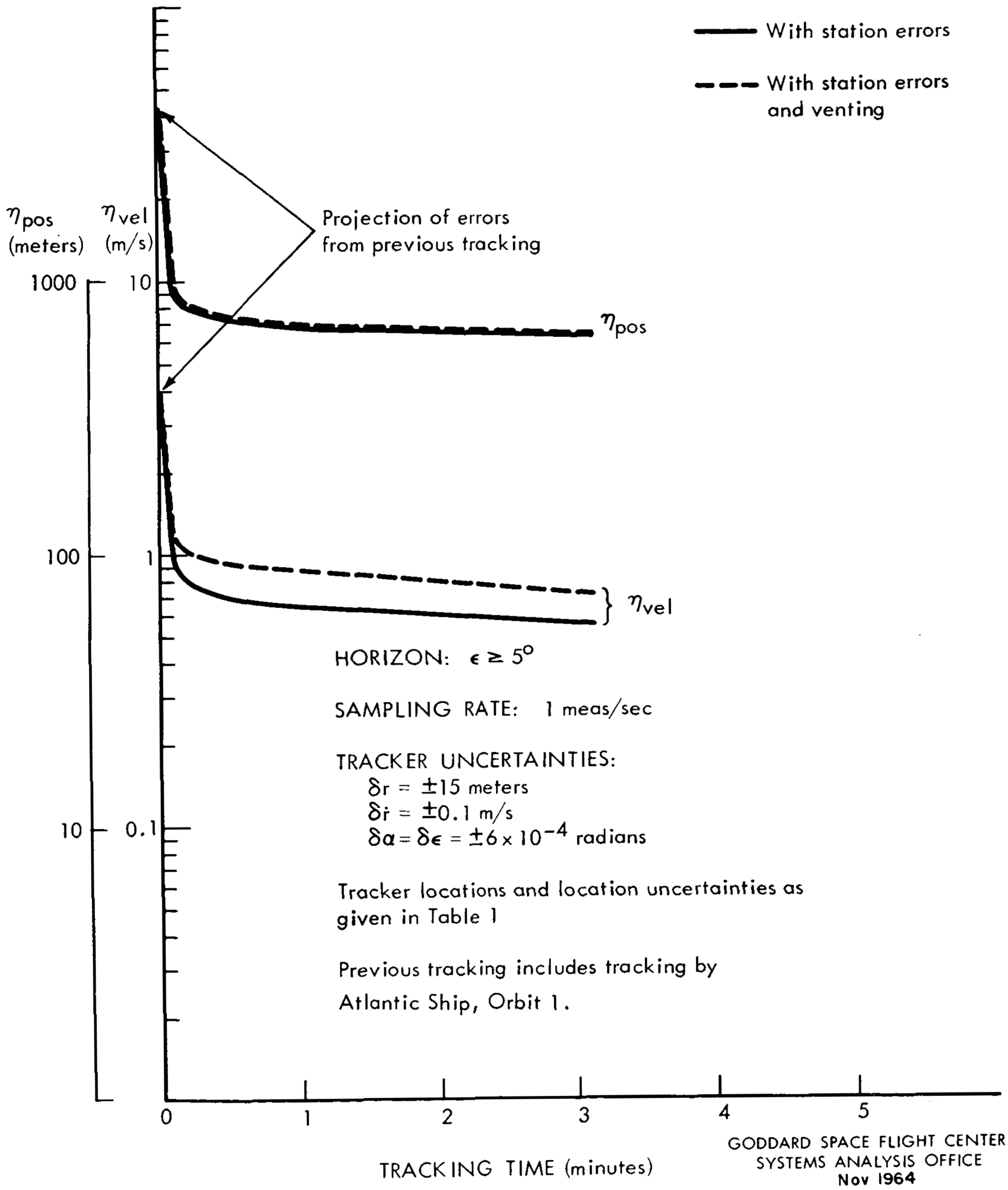

FIGURE 7

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 72°, Height 185 km
Variable Acquisition by
Indian Ocean Ship, Orbit 1

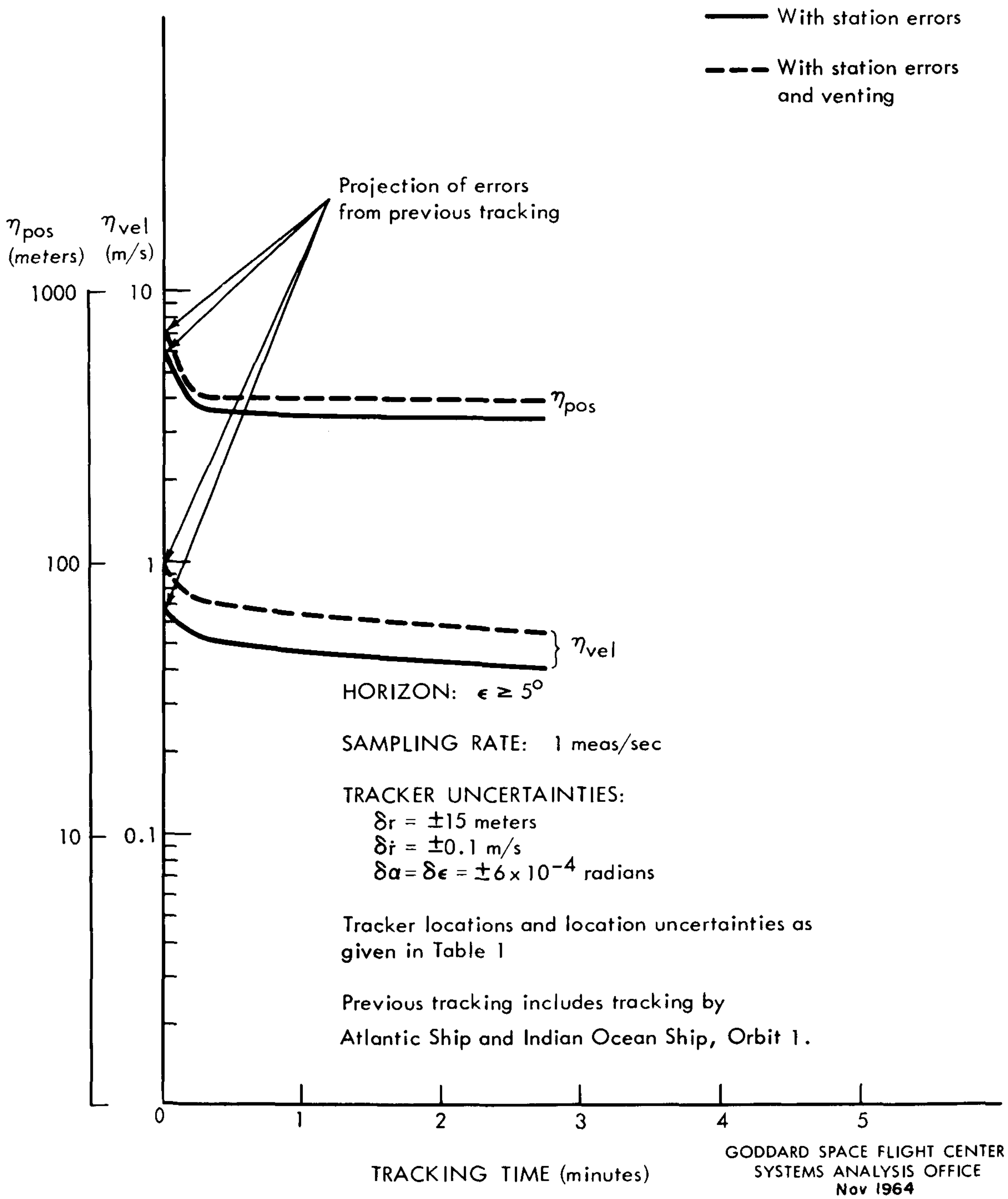

FIGURE 8

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 72°, Height 185 km
Variable Acquisition by
Carnarvon, Orbit 1

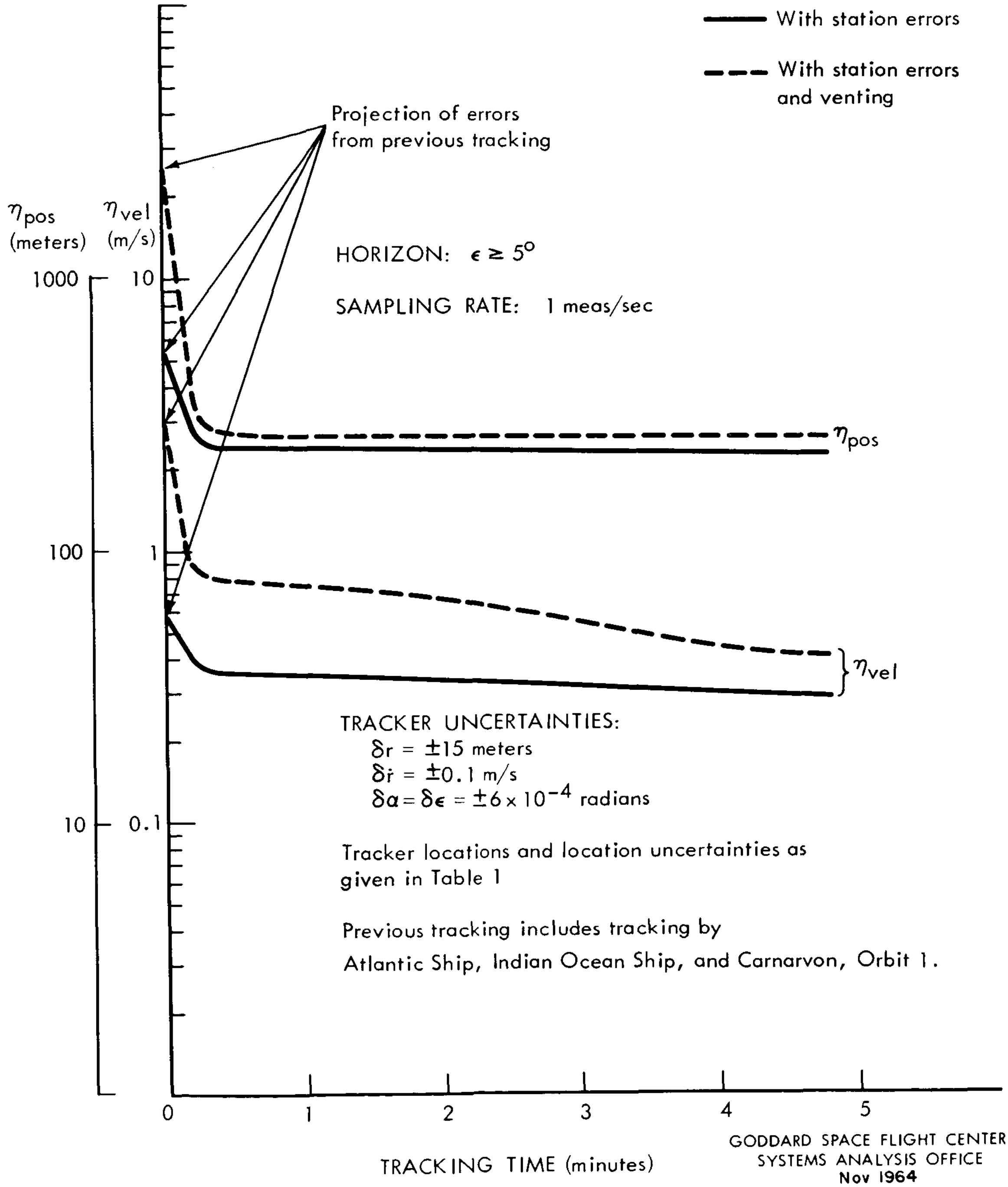

FIGURE 9

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 72°, Height 185 km
Variable Acquisition by
Guaymas, Orbit 1

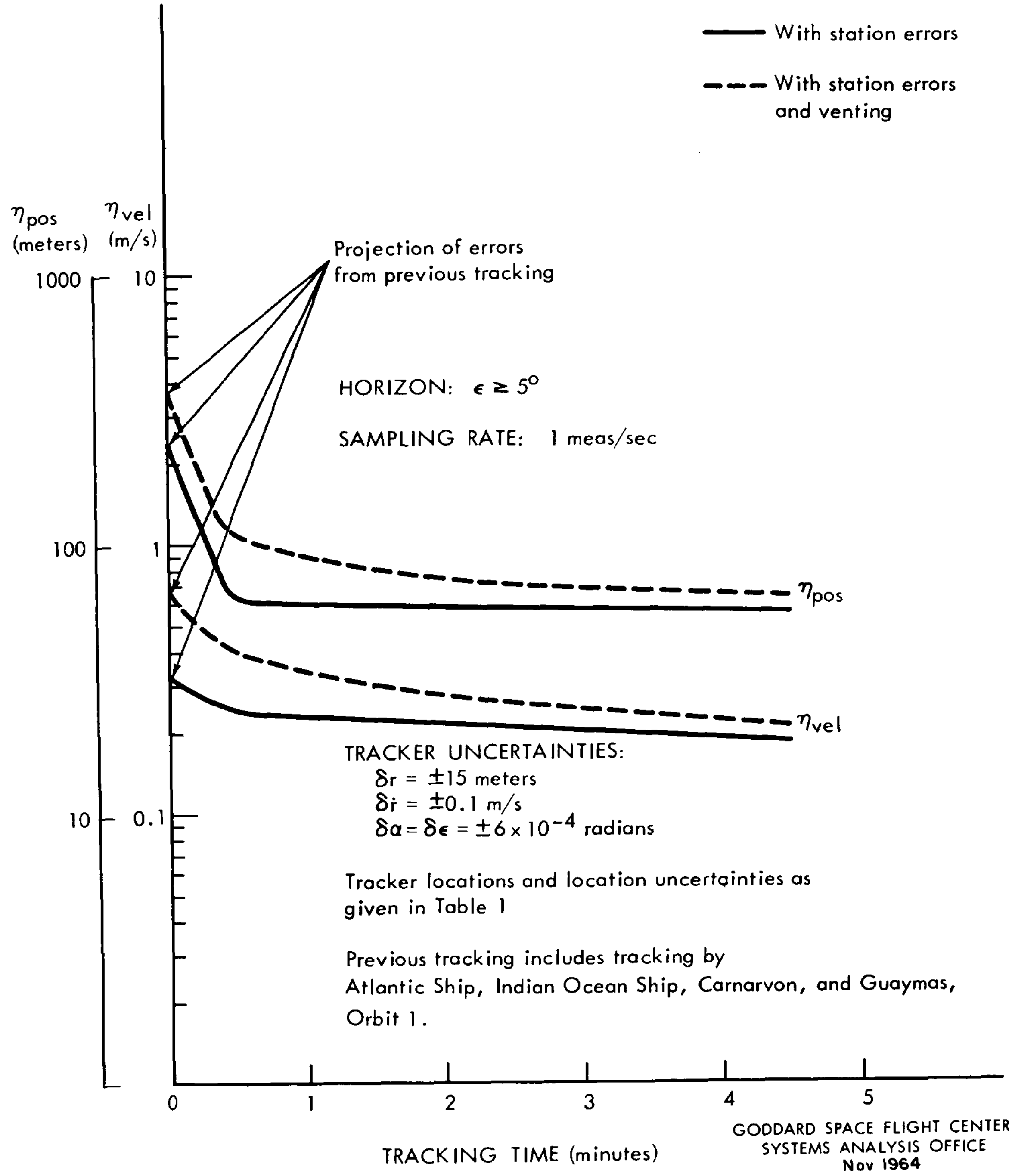

FIGURE 10

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 72°, Height 185 km
Variable Acquisition by
Cape Kennedy, Orbit 2

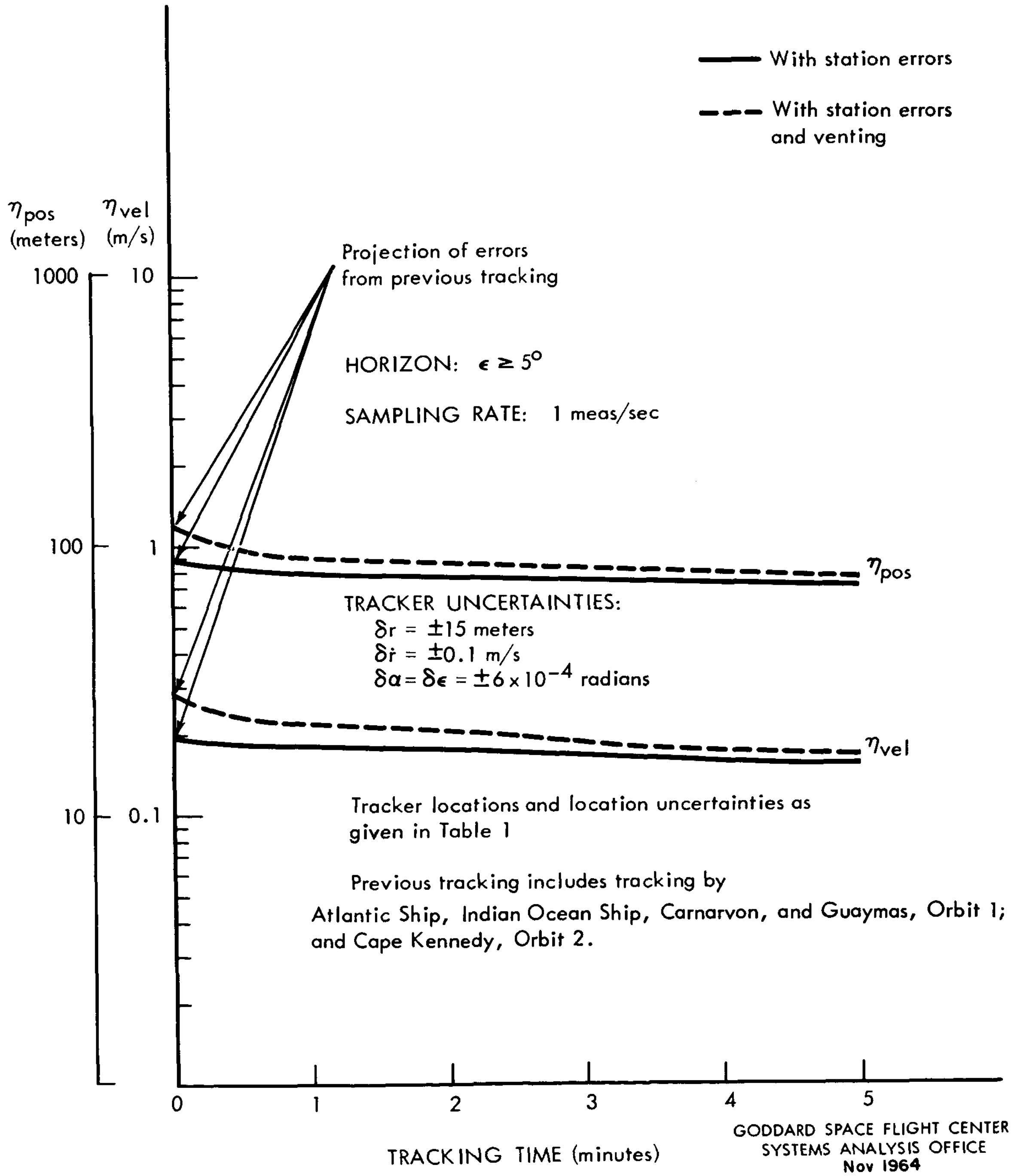

FIGURE 11

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 72°, Height 185 km
Variable Acquisition by
Bermuda, Orbit 2

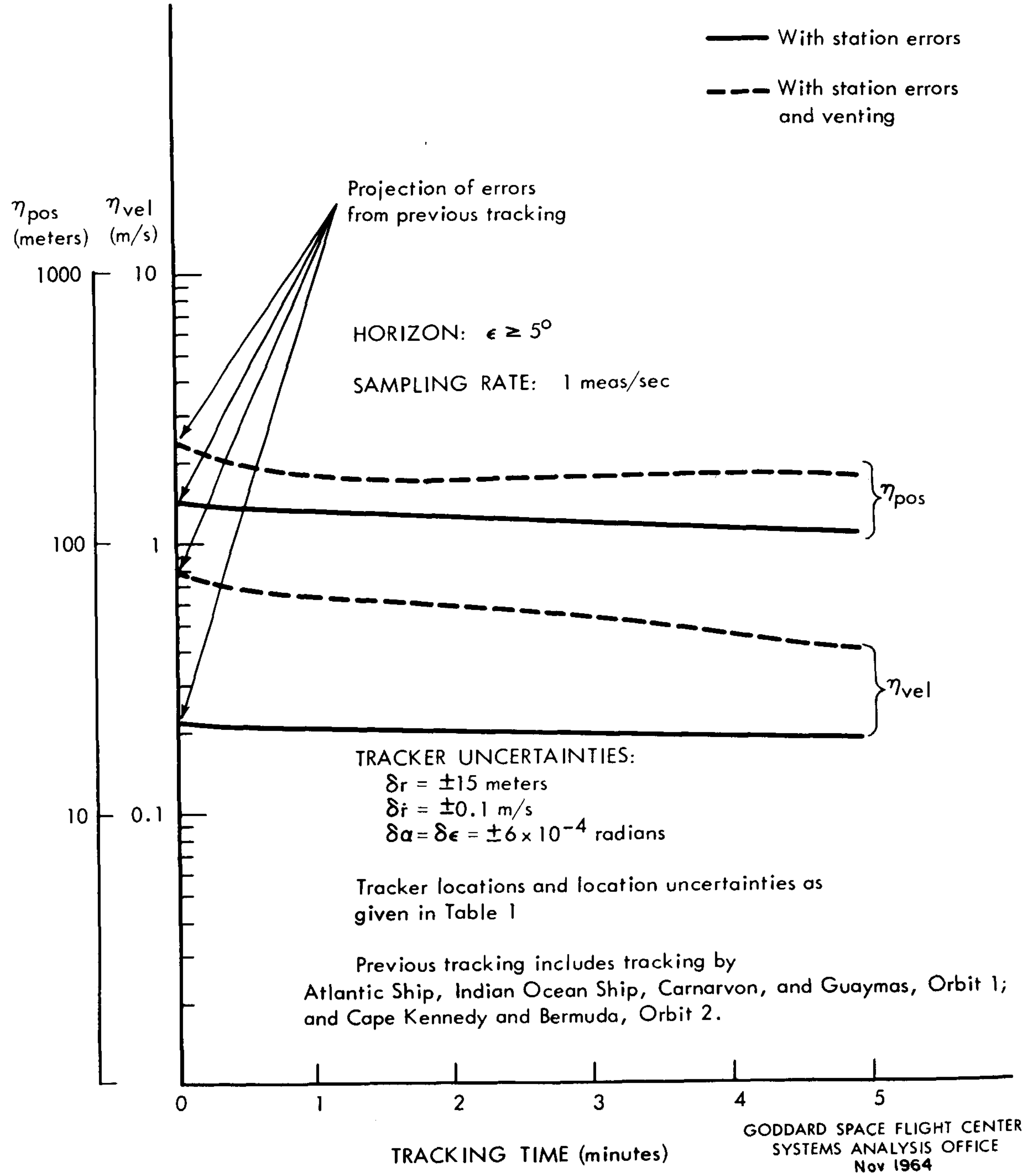

FIGURE 12

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 72°, Height 185 km
Variable Acquisition by
Indian Ocean Ship, Orbit 2

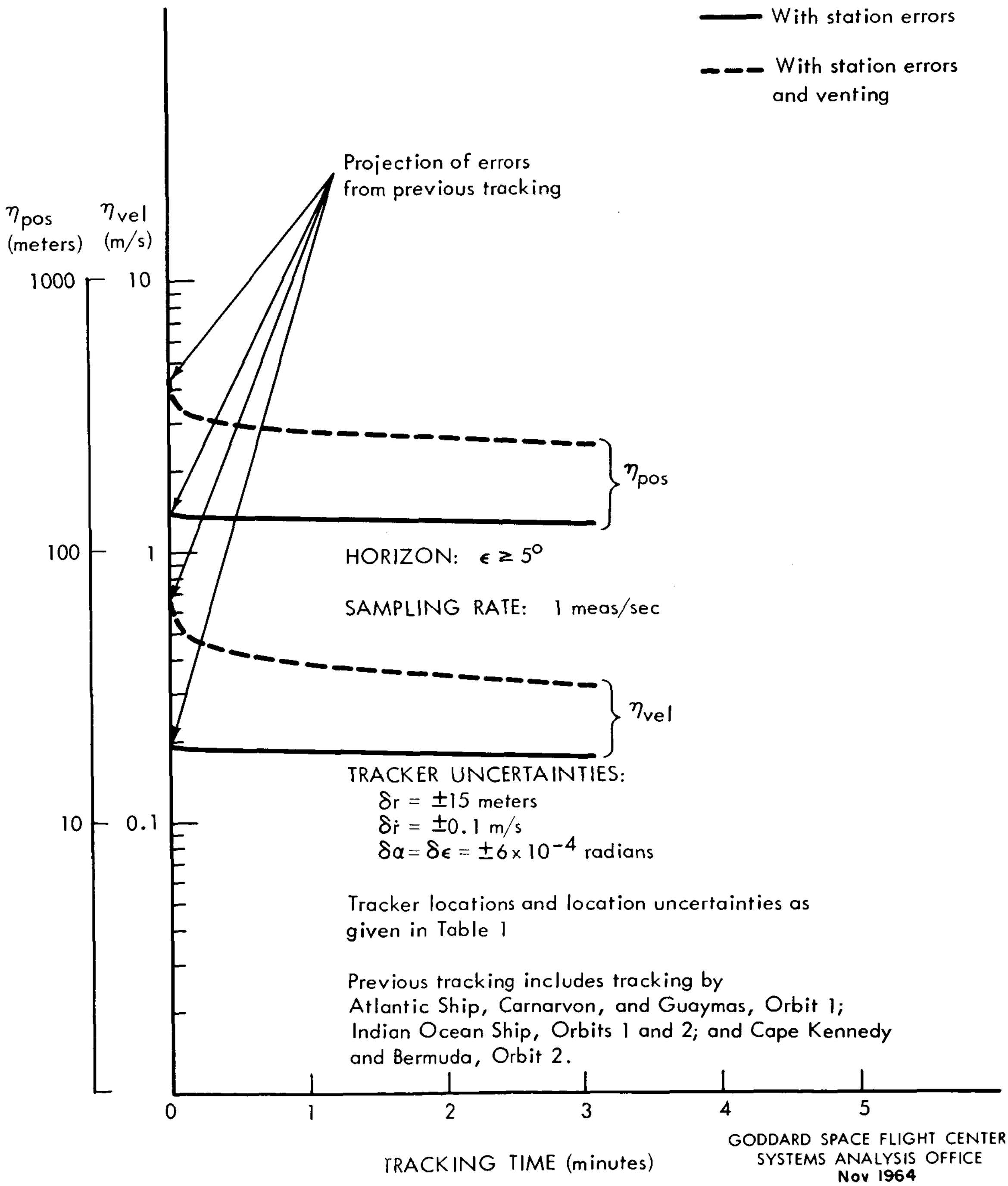

FIGURE 13

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 72°, Height 185 km
Variable Acquisition by
Carnarvon, Orbit 2

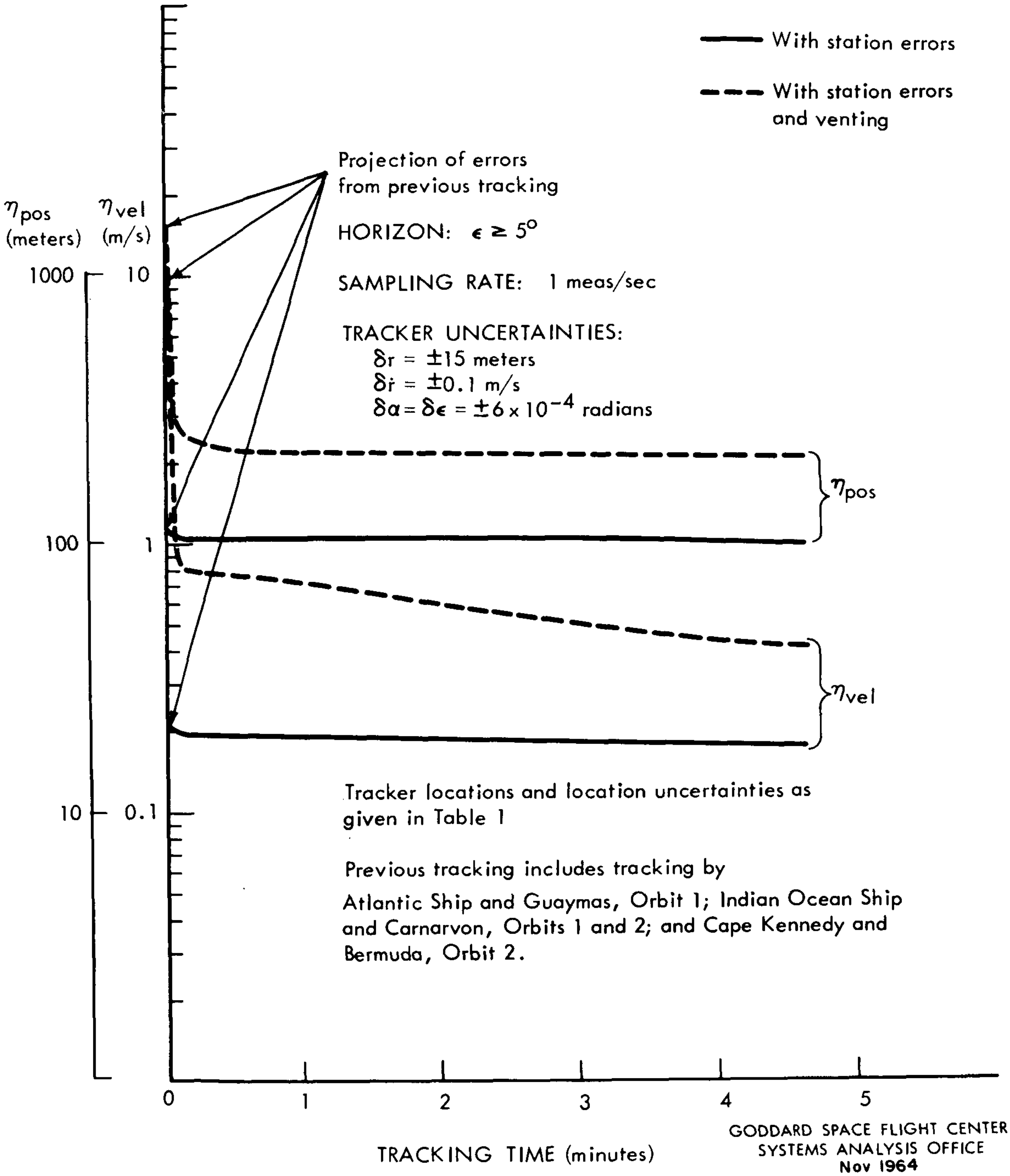

FIGURE 14

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 72°, Height 185 km
Variable Acquisition by
Guaymas, Orbit 2

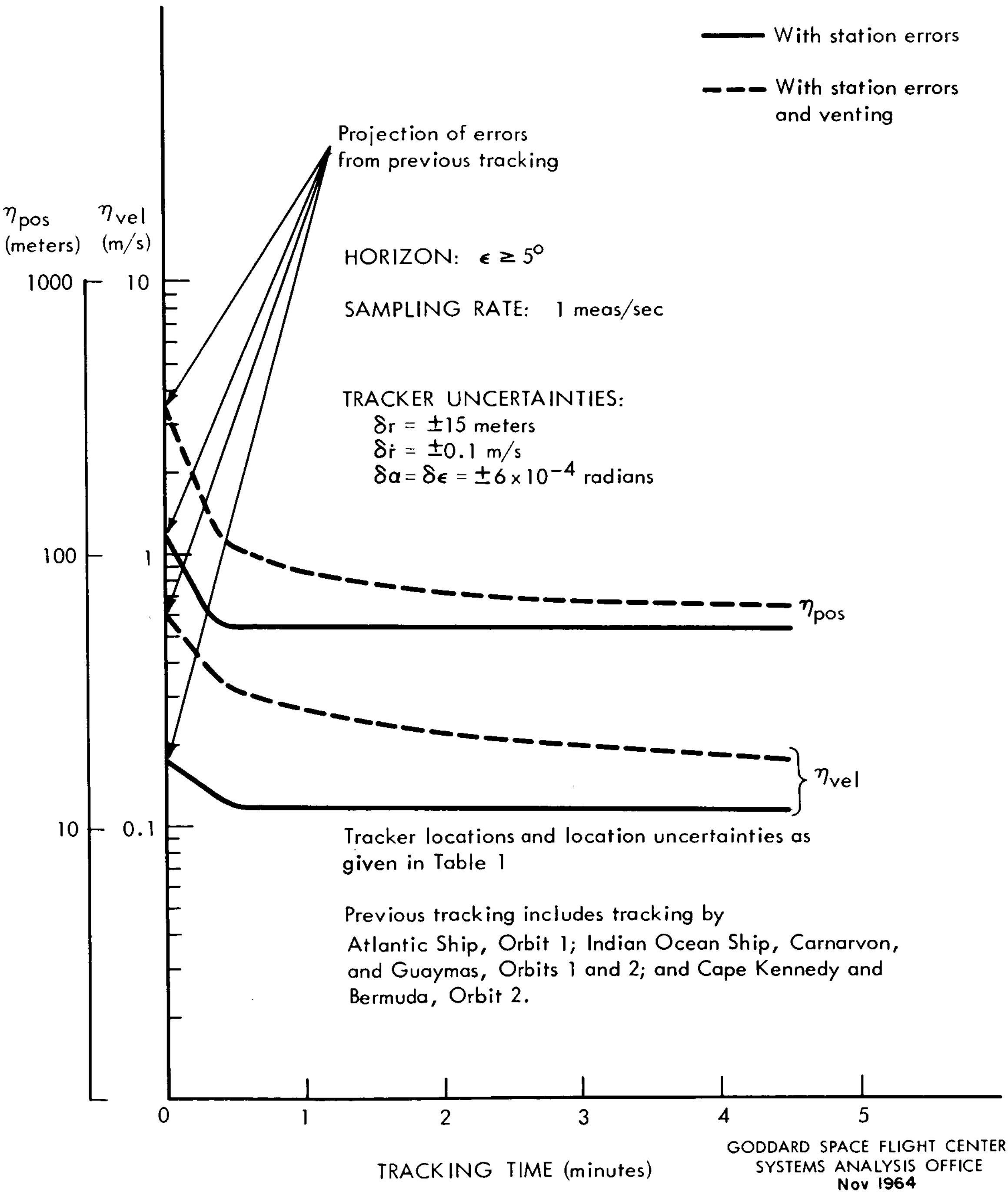

FIGURE 15

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 72°, Height 185 km
Variable Acquisition by
Cape Kennedy, Orbit 3

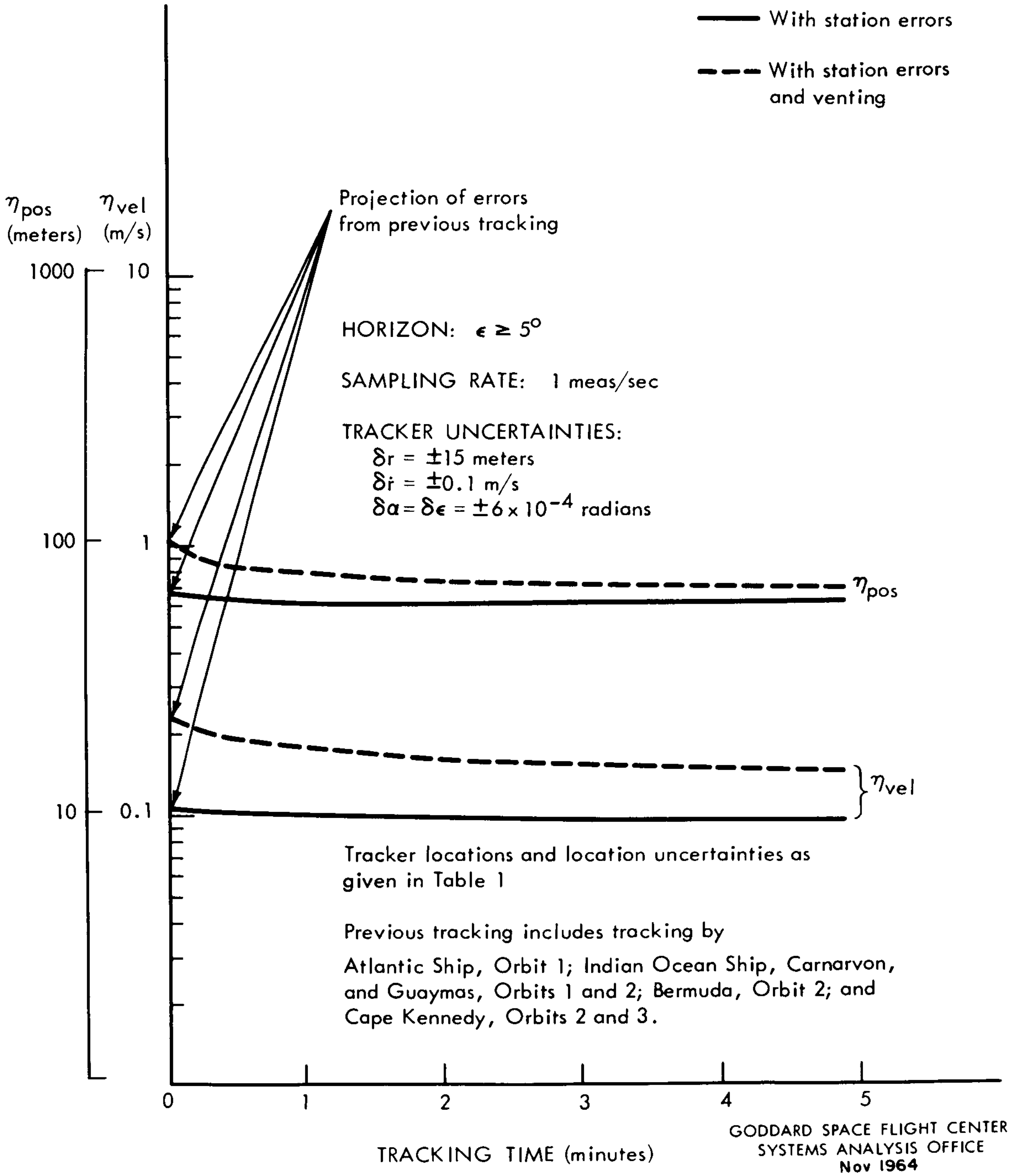

FIGURE 16

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 72°, Height 185 km
Variable Acquisition by
Bermuda, Orbit 3

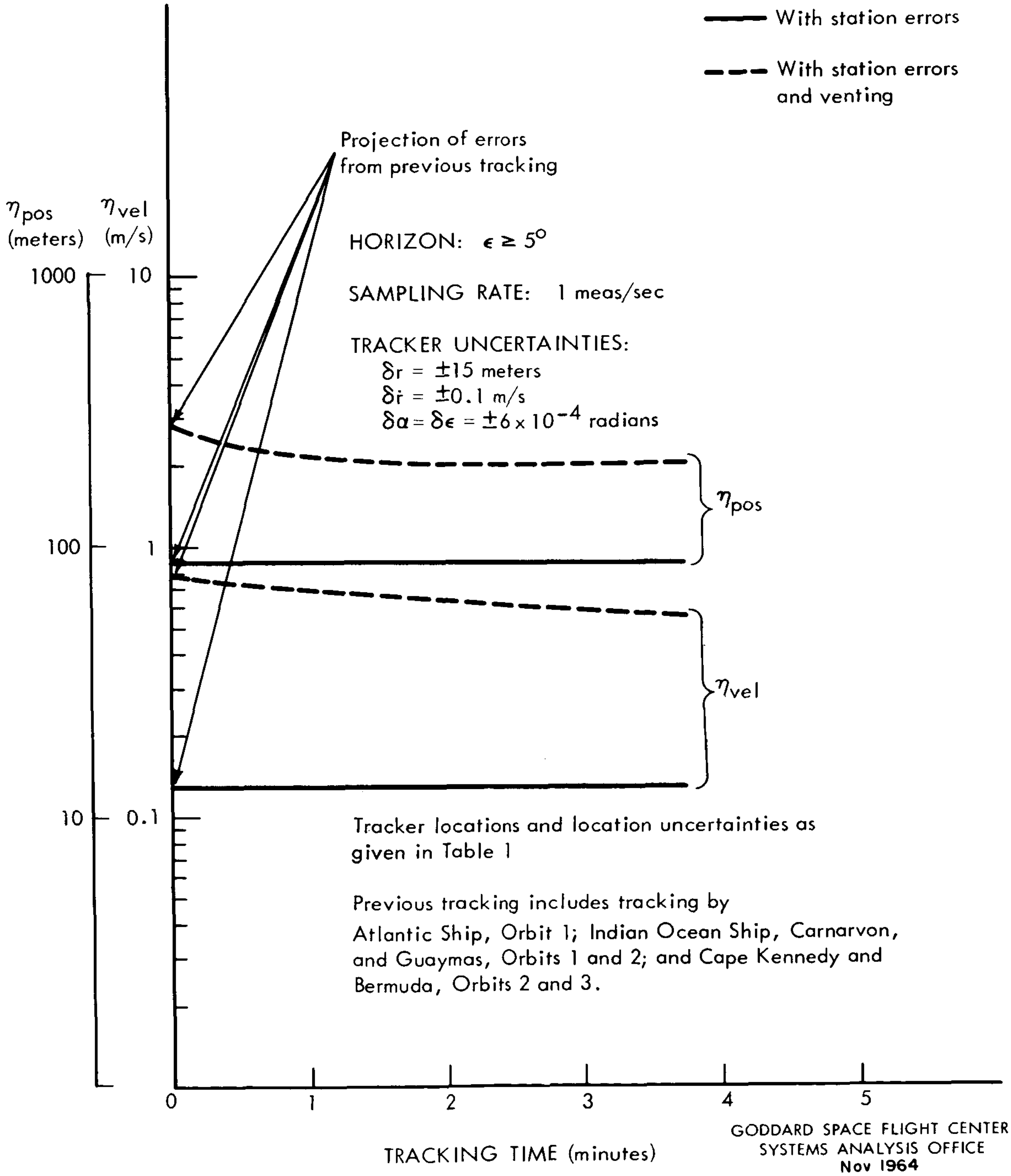

FIGURE 17

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 72°, Height 185 km
Variable Acquisition by
Indian Ocean Ship, Orbit 3

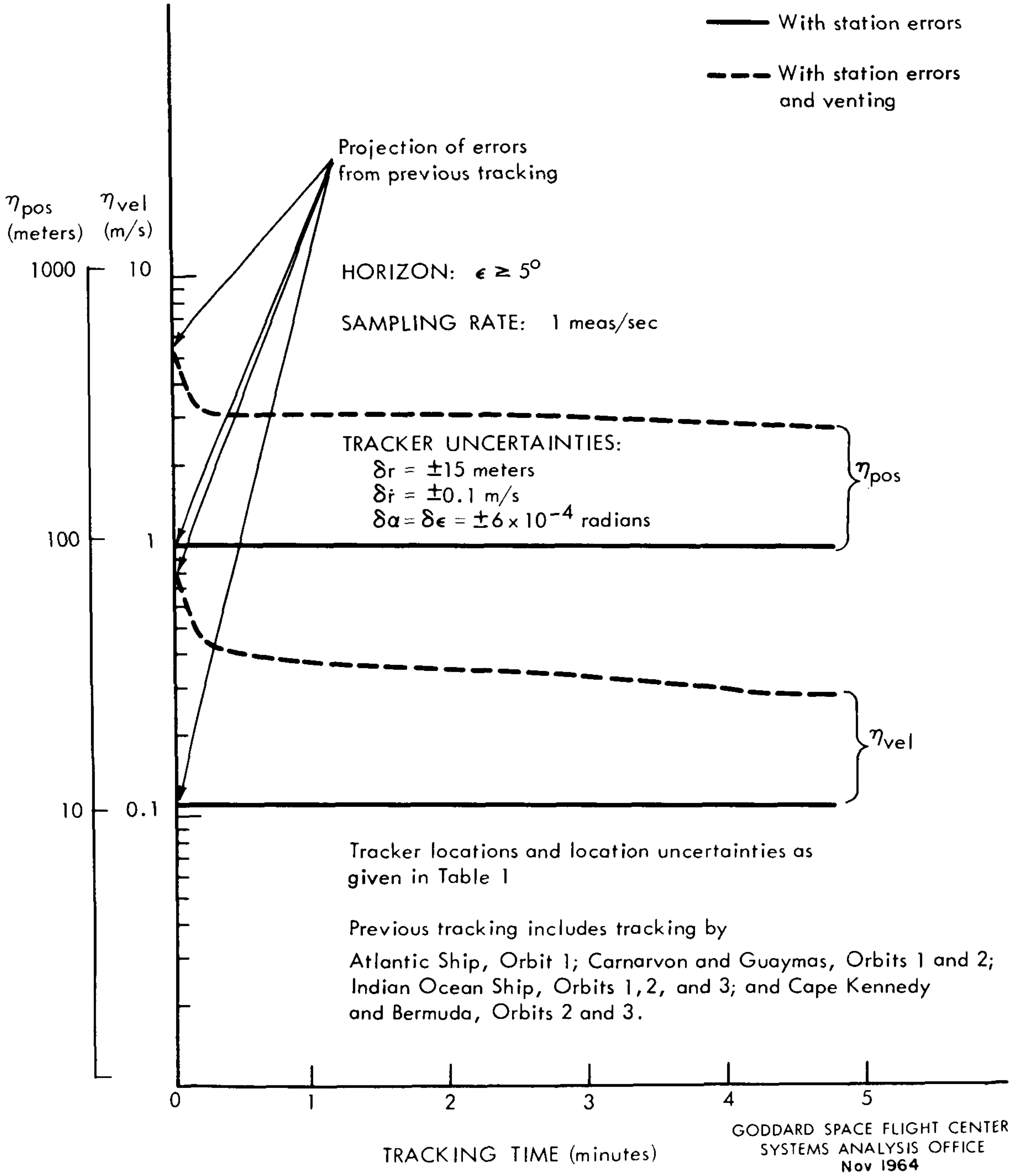

FIGURE 18

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 72°, Height 185 km
Variable Acquisition by
Carnarvon, Orbit 3

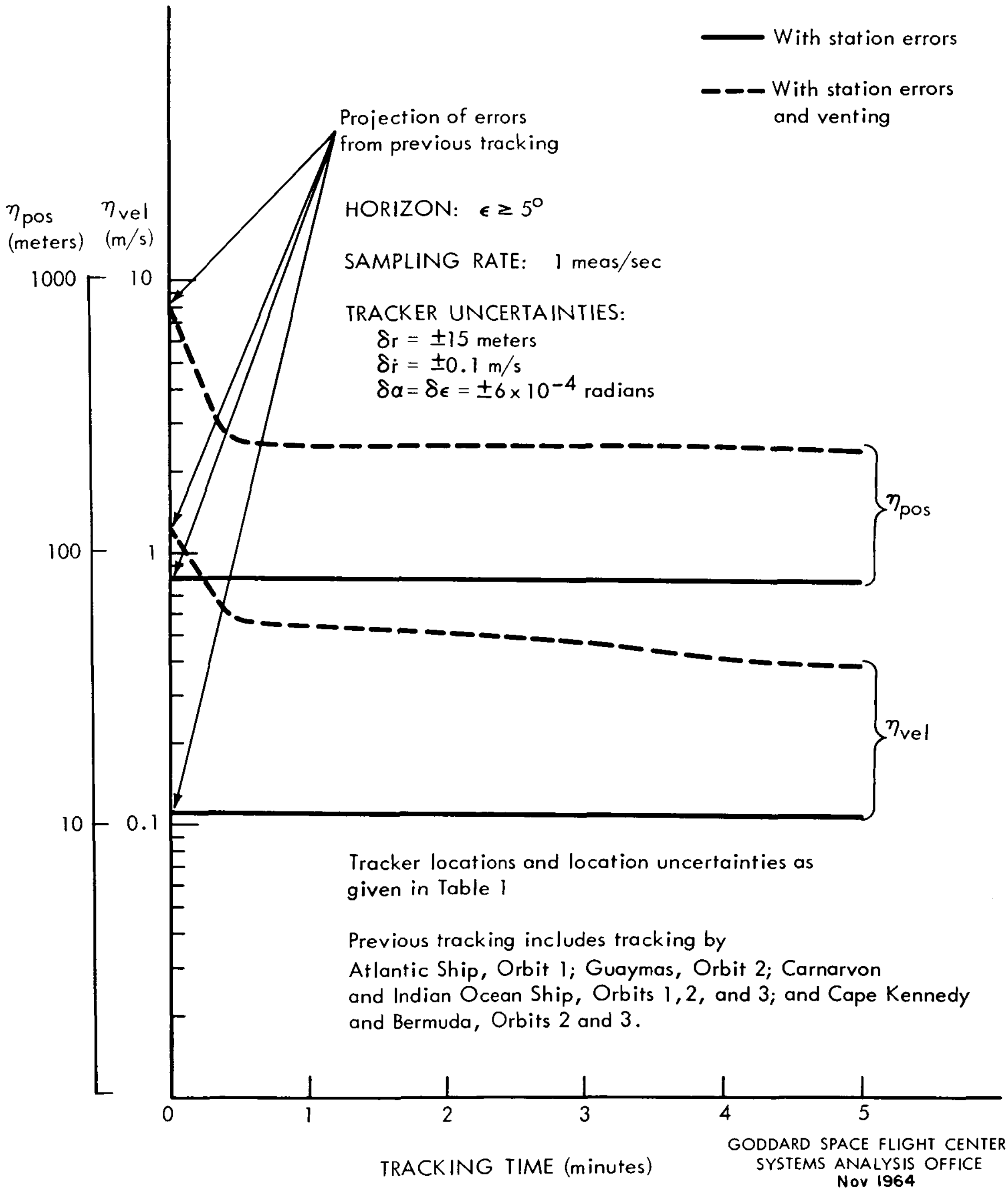

FIGURE 19

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 72^{o}, Height 185 km
Variable Acquisition by
Hawaii, Orbit 3

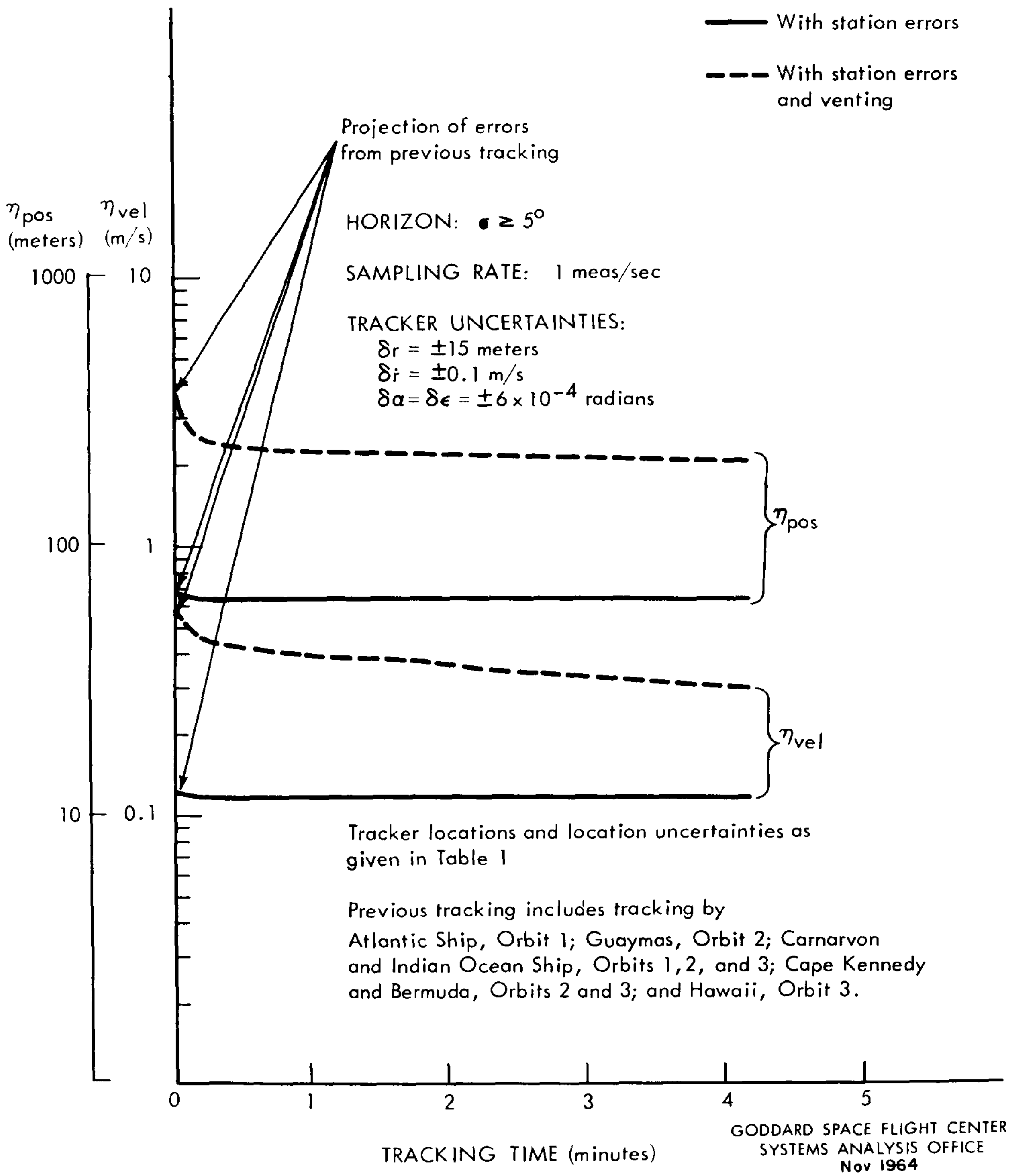

FIGURE 20

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 72°, Height 185 km
Variable Acquisition by
Guaymas, Orbit 3

FIGURES 21-39

ERRORS IN SPACECRAFT POSITION AND VELOCITY

APOLLO PARKING ORBIT, LAUNCH AZIMUTH 90°, HEIGHT 185 KM.

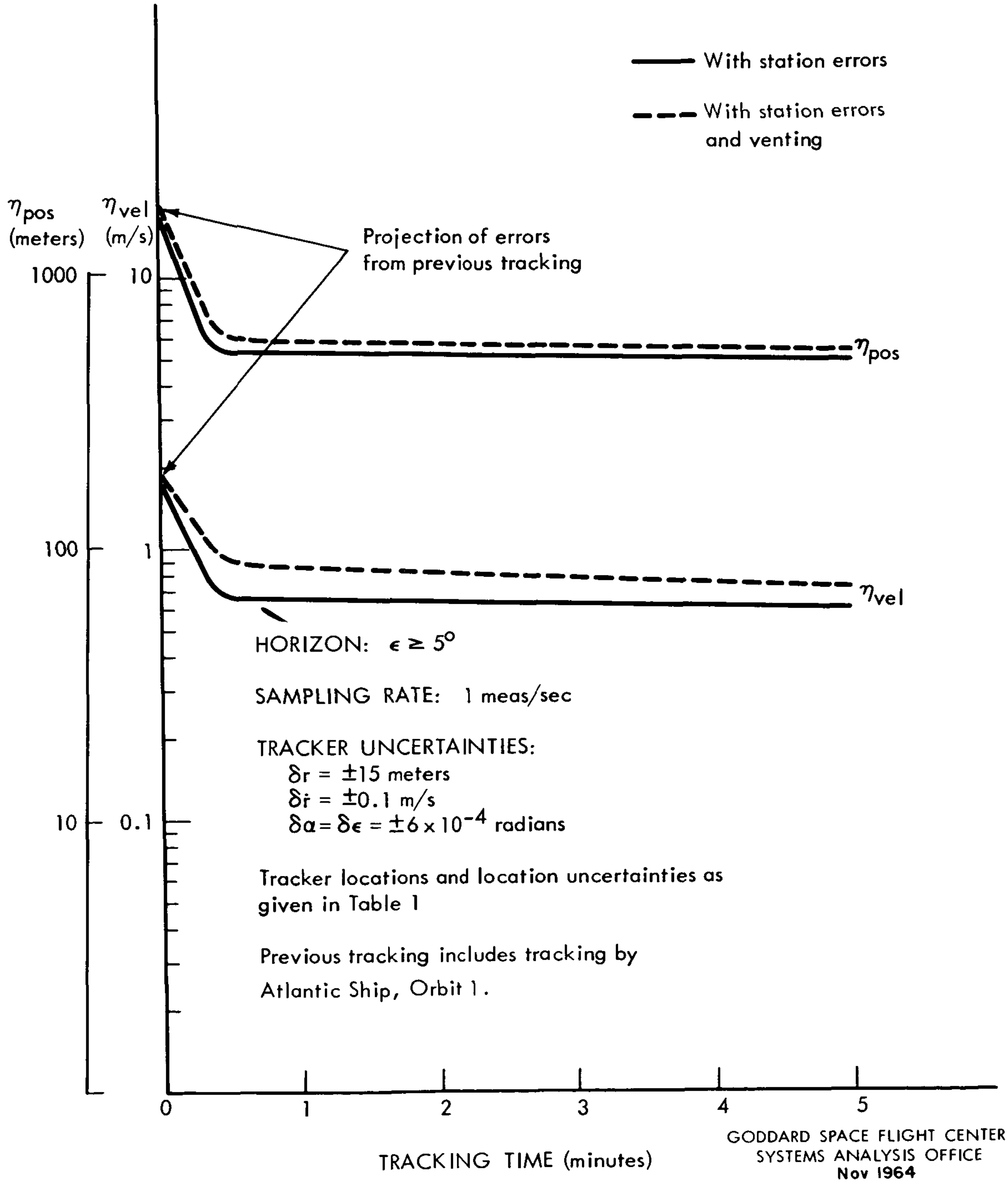

FIGURE 21

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 90°, Height 185 km
Variable Acquisition by
Indian Ocean Ship, Orbit 1

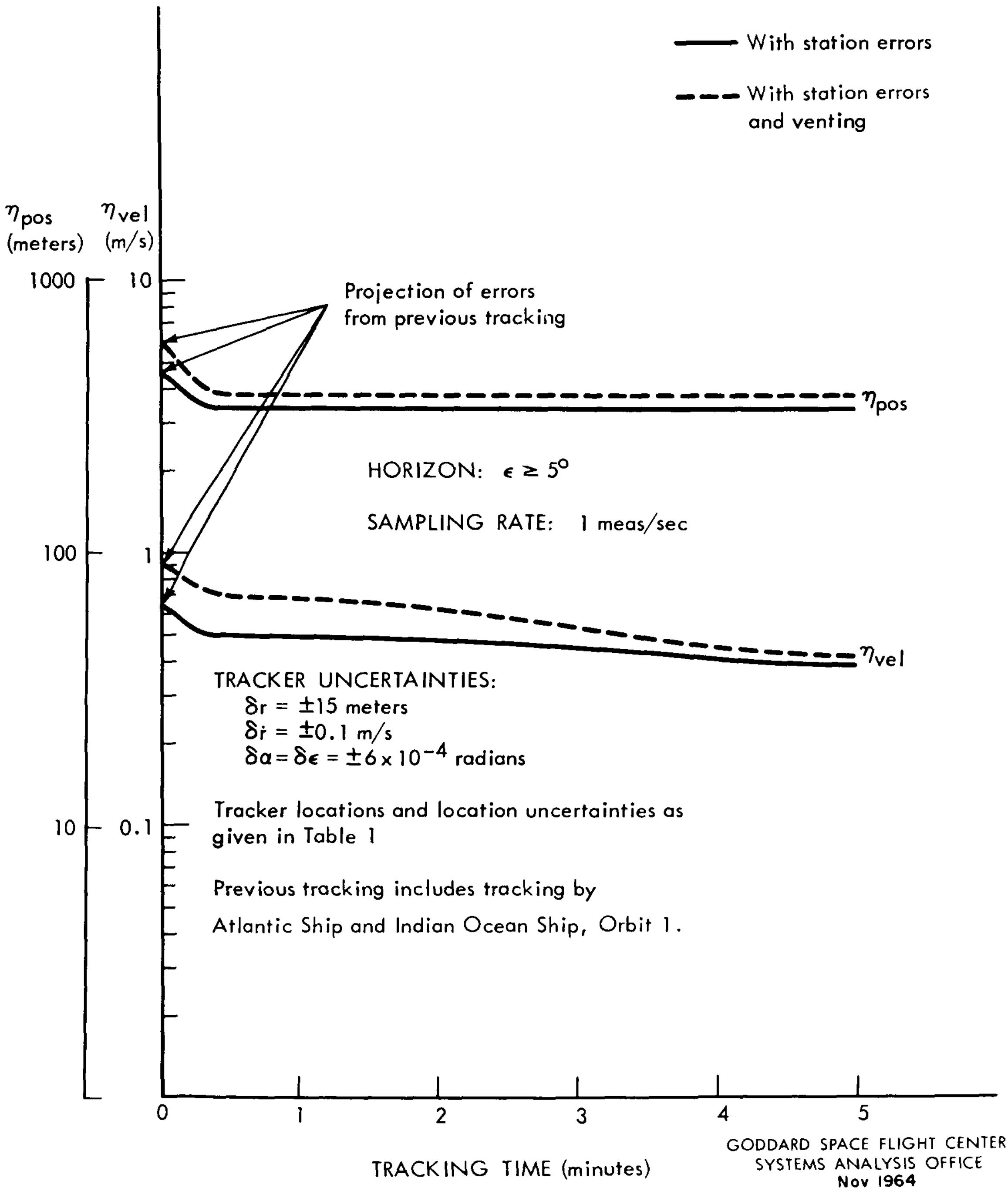

FIGURE 22

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 90°, Height 185 km
Variable Acquisition by
Carnarvon, Orbit 1

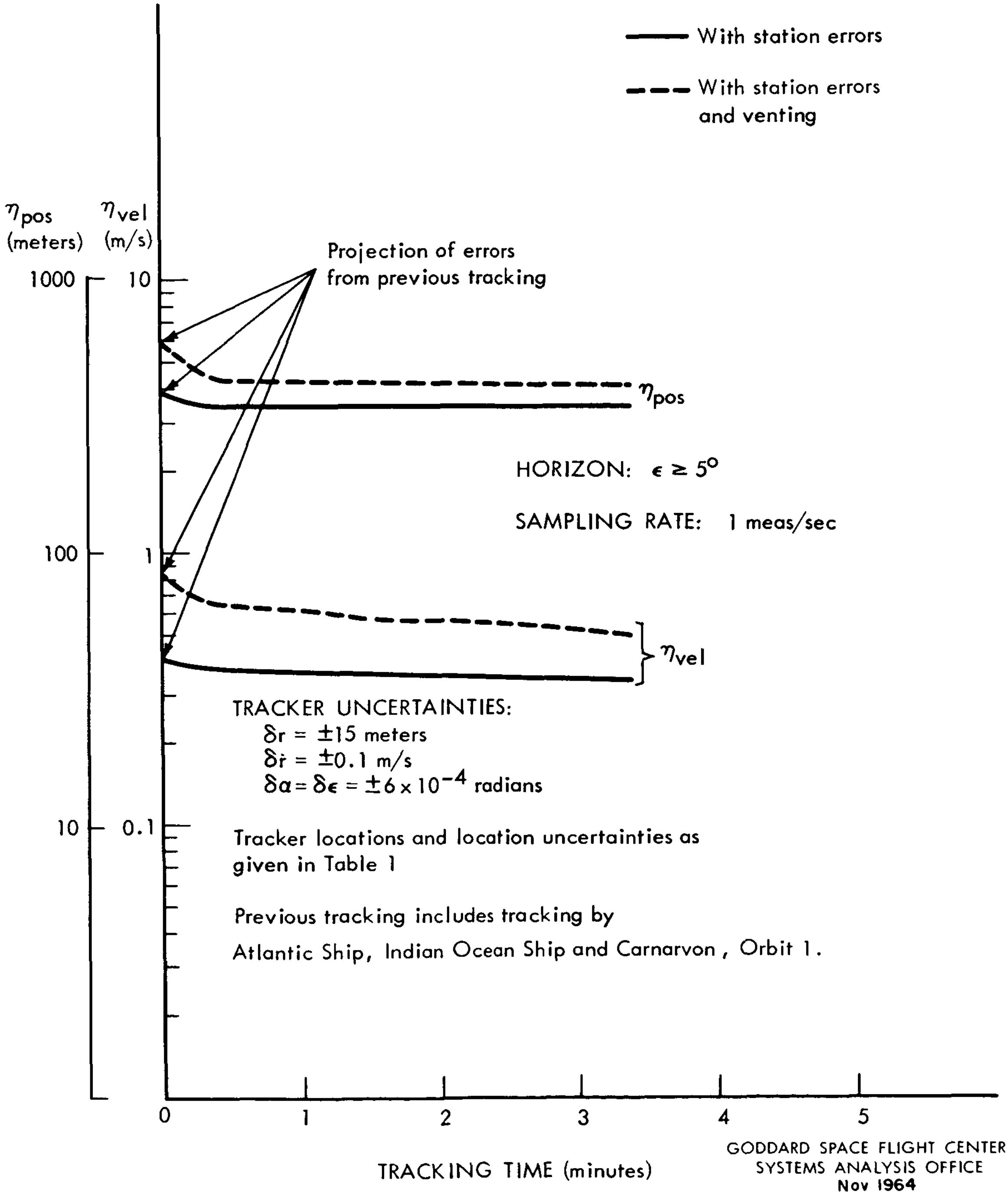

FIGURE 23

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 90°, Height 185 km
Variable Acquisition by
Hawaii, Orbit 1

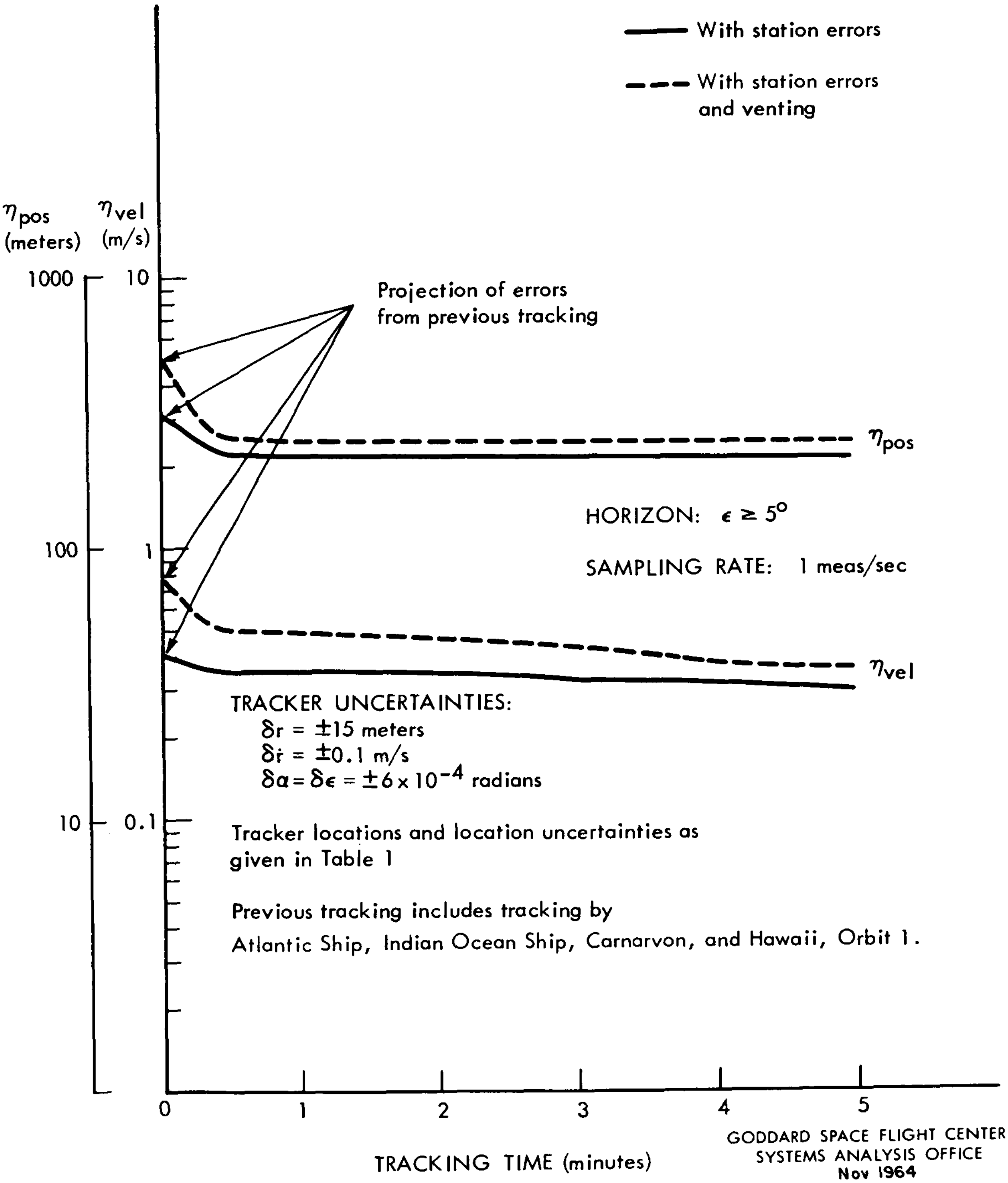

FIGURE 24

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 90°, Height 185 km
Variable Acquisition by
Guaymas, Orbit 1

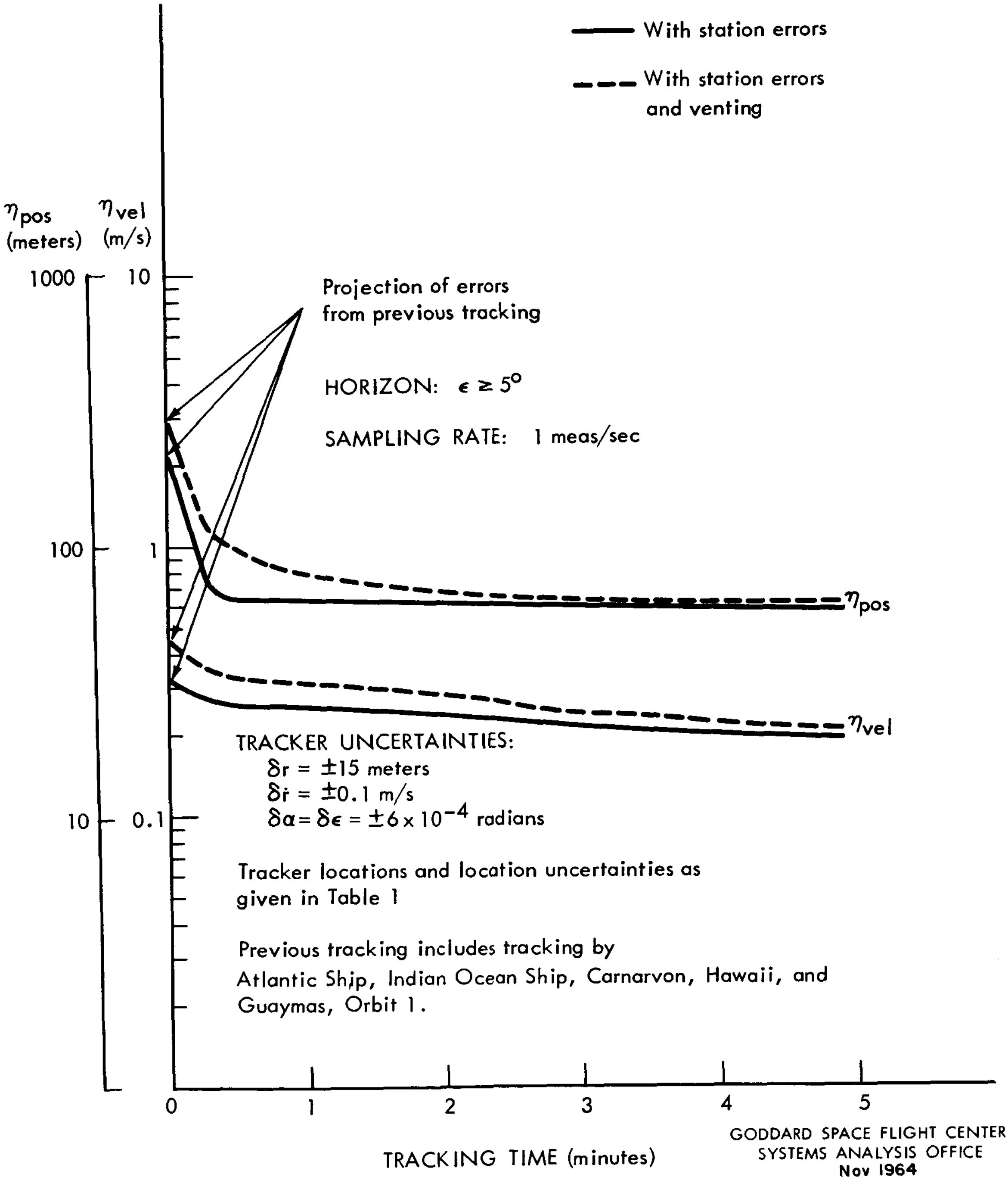

FIGURE 25

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 90°, Height 185 km
Variable Acquisition by

Cape Kennedy, Orbit 2

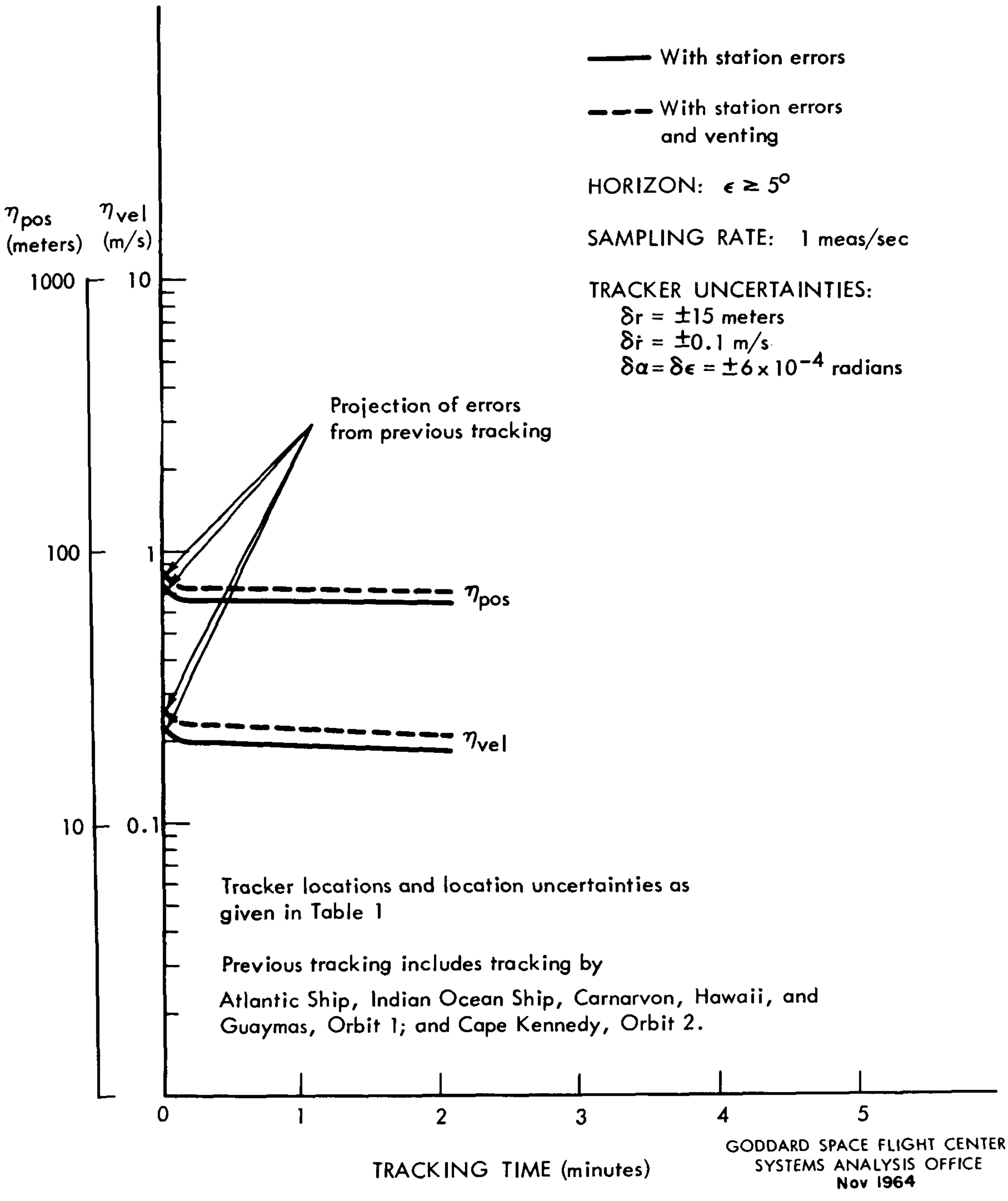

FIGURE 26

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 90°, Height 185 km
Variable Acquisition by
Bermuda, Orbit 2

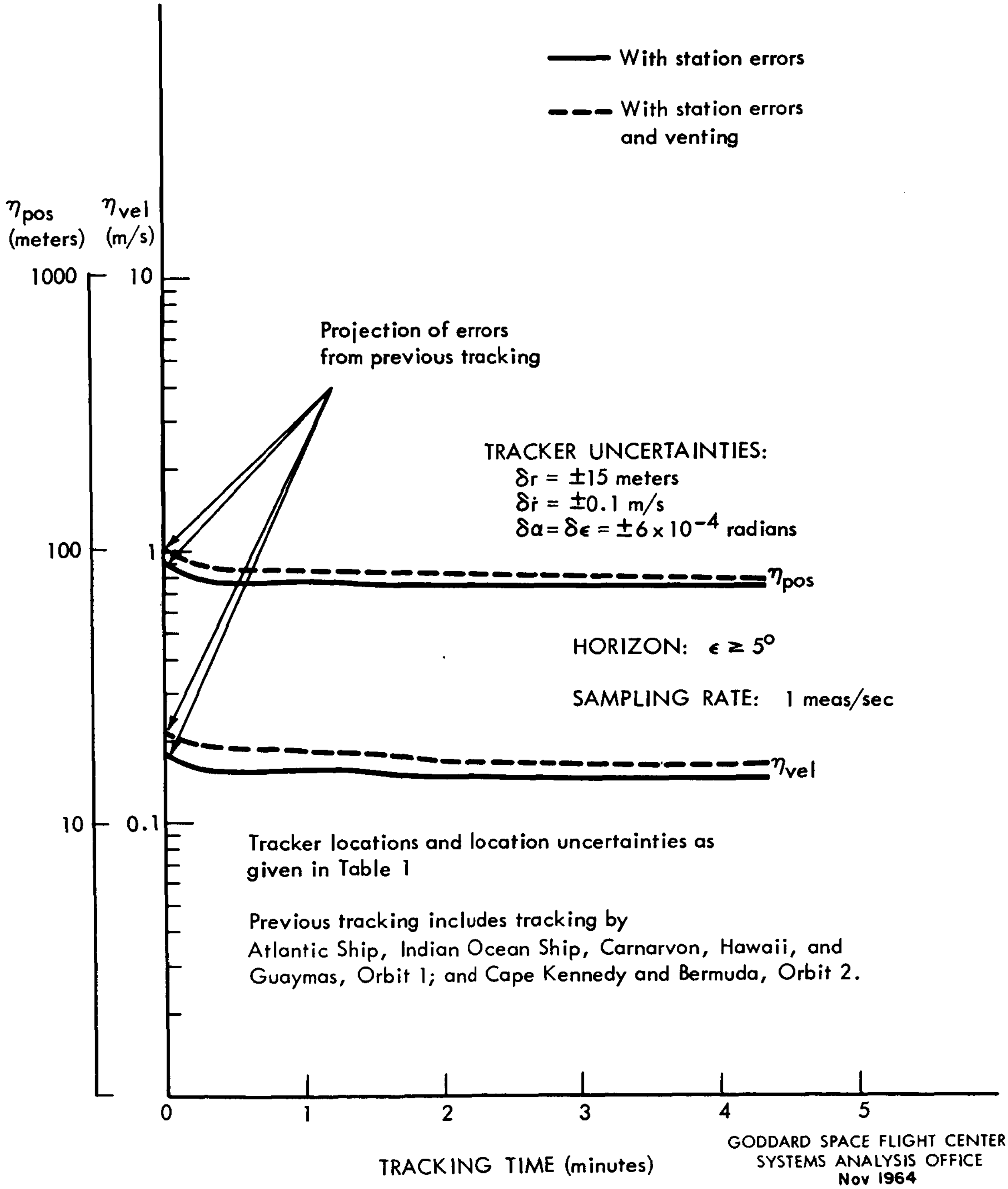

FIGURE 27

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 90°, Height 185 km
Variable Acquisition by
Antigua, Orbit 2

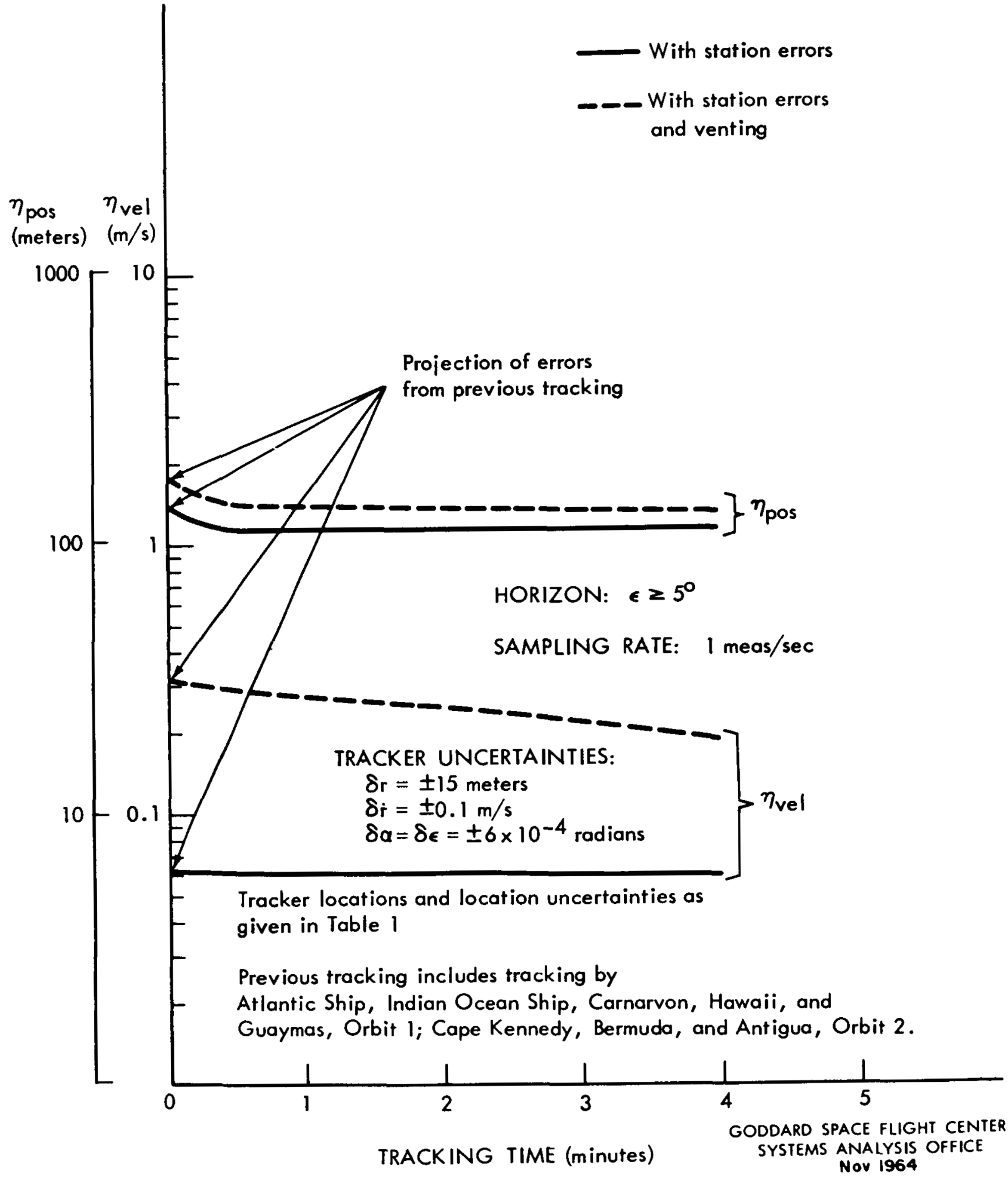

FIGURE 28

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 90°, Height 185 km
Variable Acquisition by
Ascension, Orbit 2

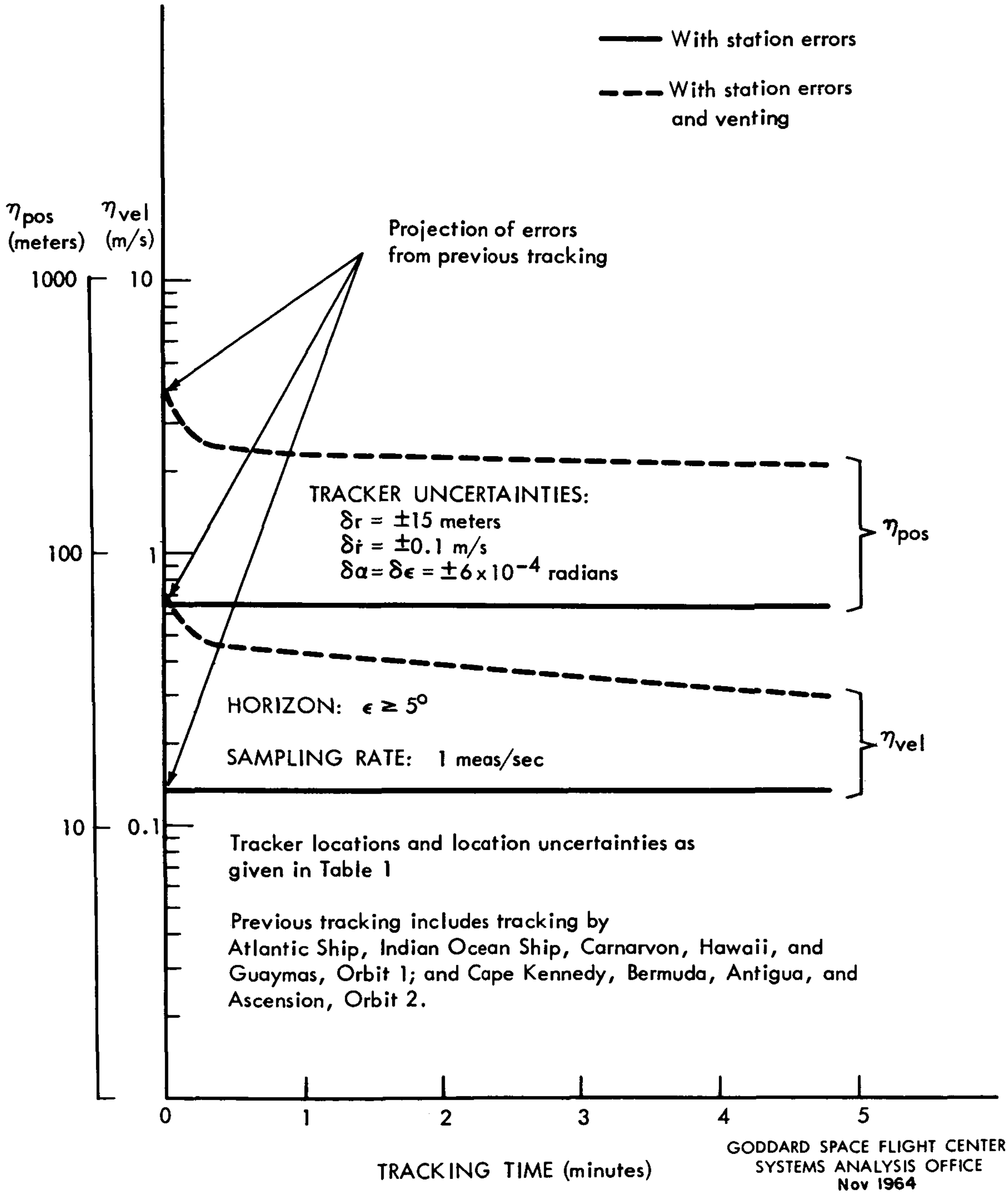

FIGURE 29

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 90°, Height 185 km
Variable Acquisition by
Indian Ocean Ship, Orbit 2

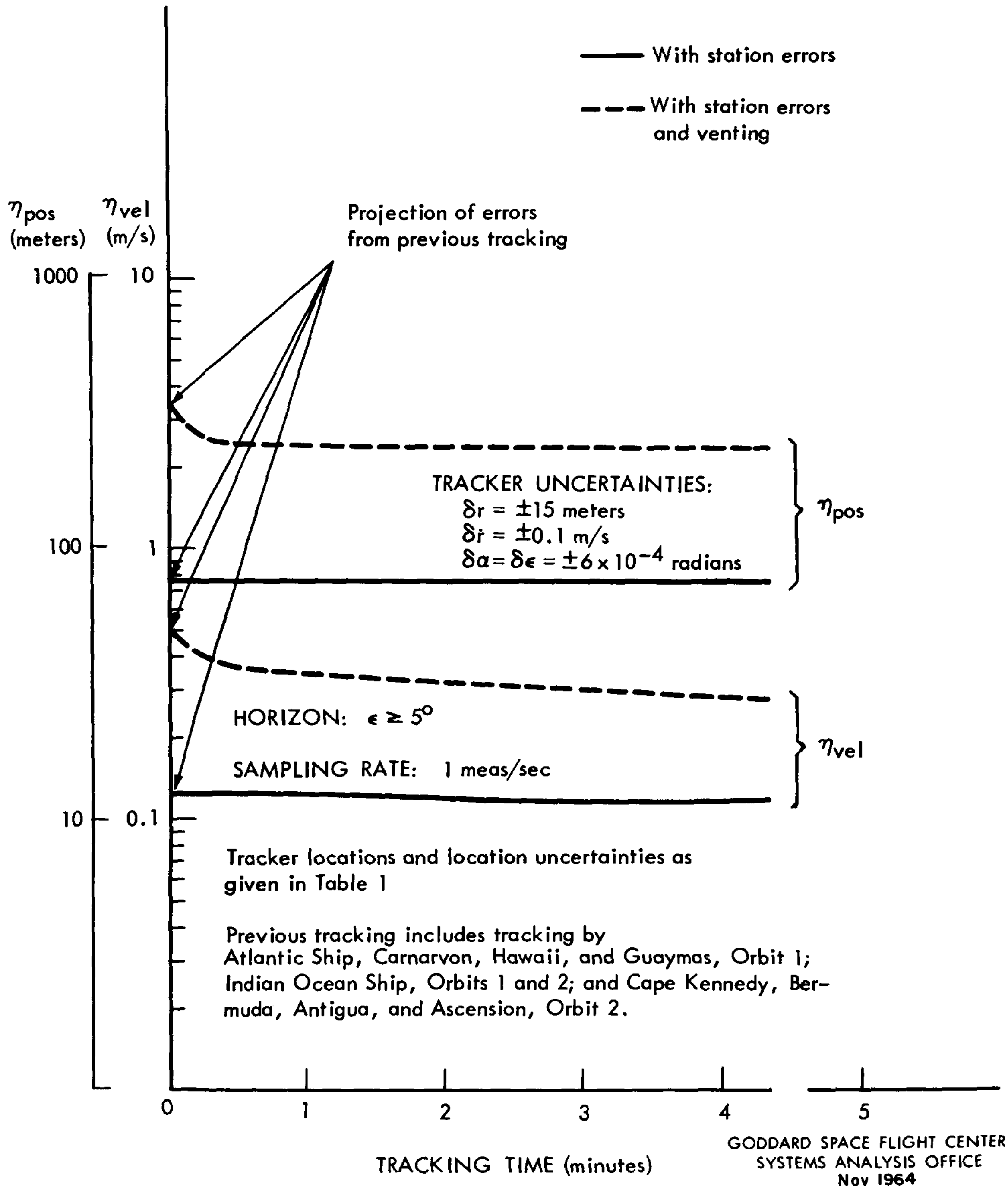

FIGURE 30

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 90°, Height 185 km
Variable Acquisition by
Carnarvon, Orbit 2

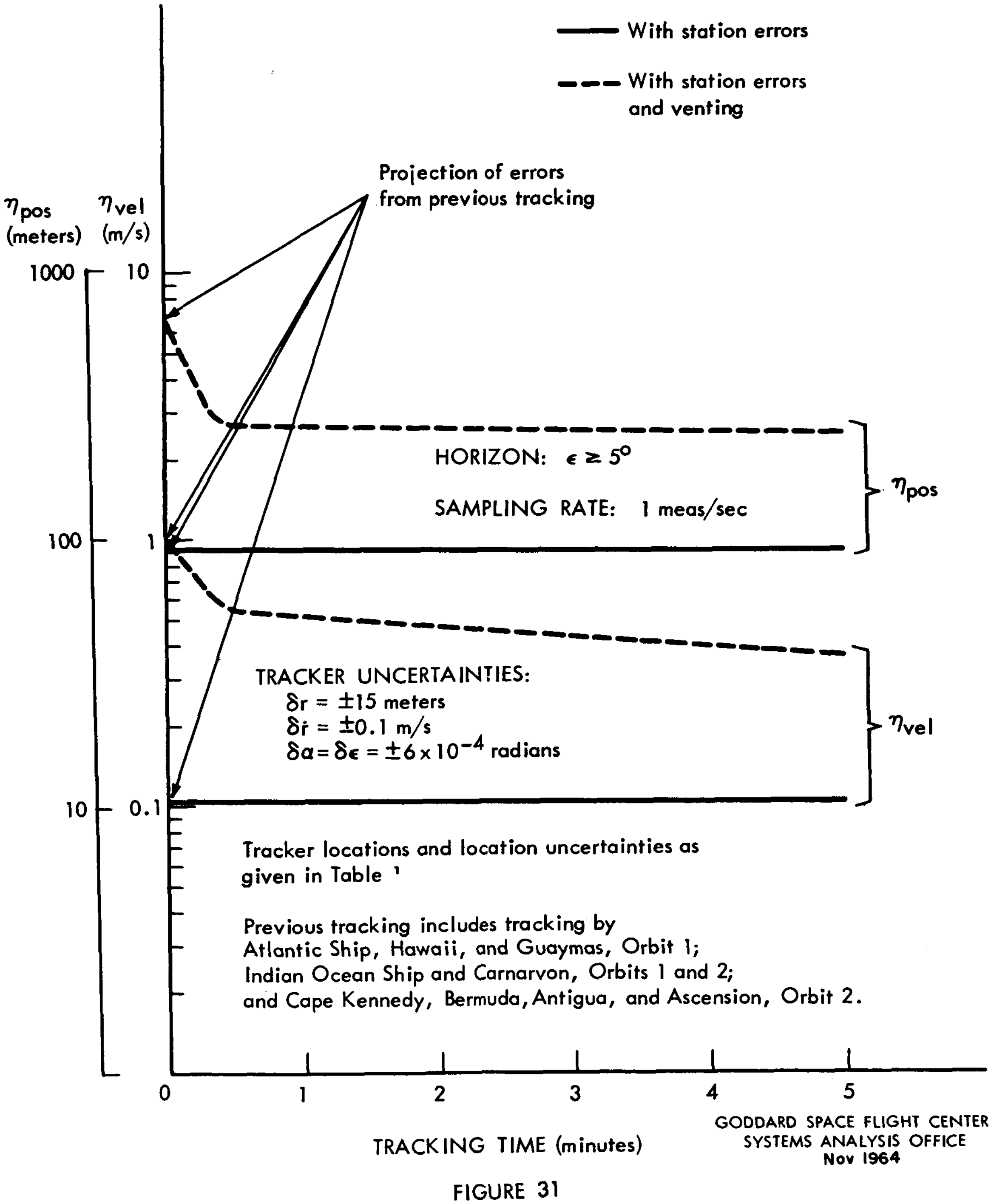

FIGURE 31

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 90°, Height 185 km
Variable Acquisition by
Hawaii, Orbit 2

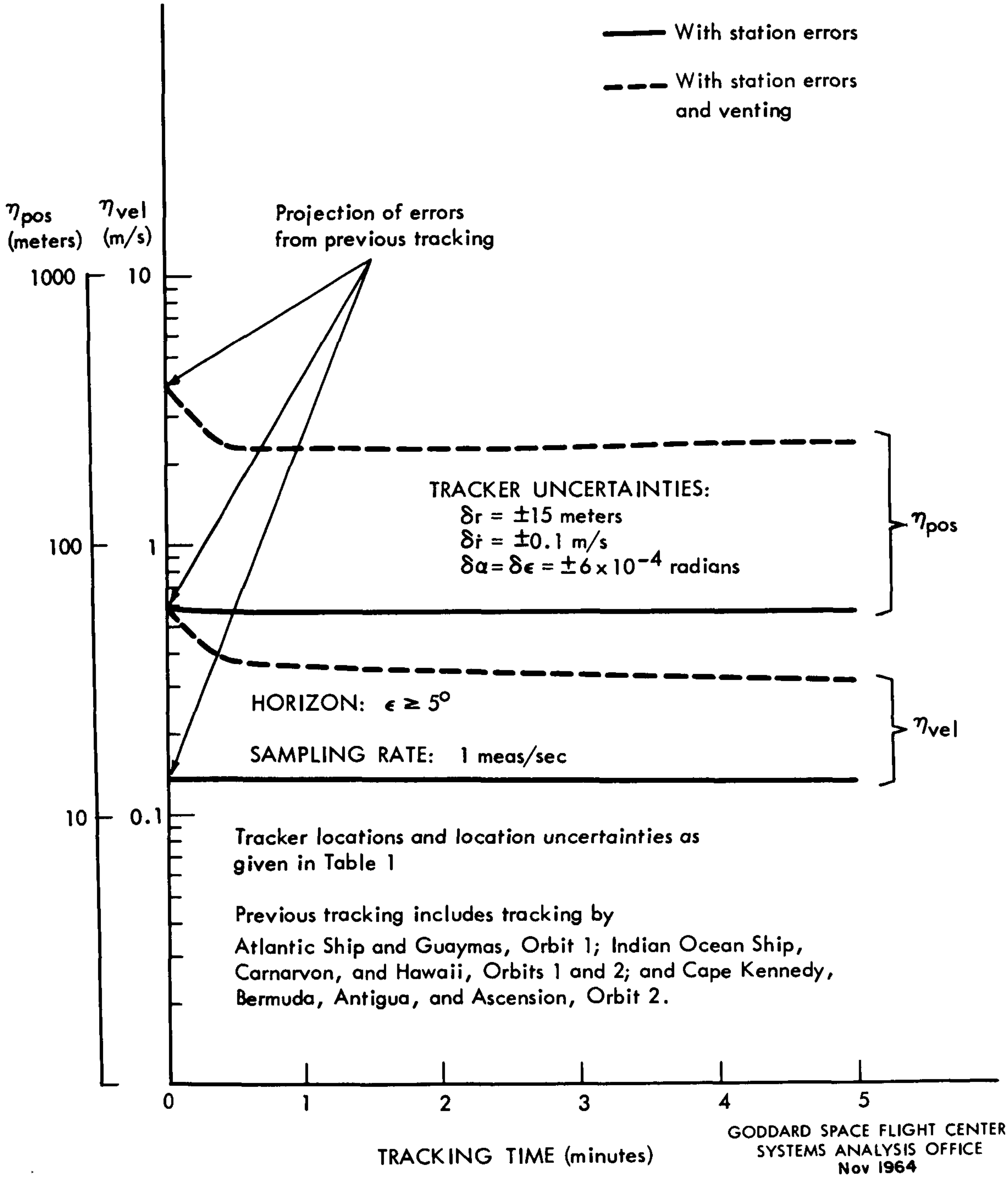

FIGURE 32

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 90°, Height 185 km
Variable Acquisition by
Guaymas, Orbit 2

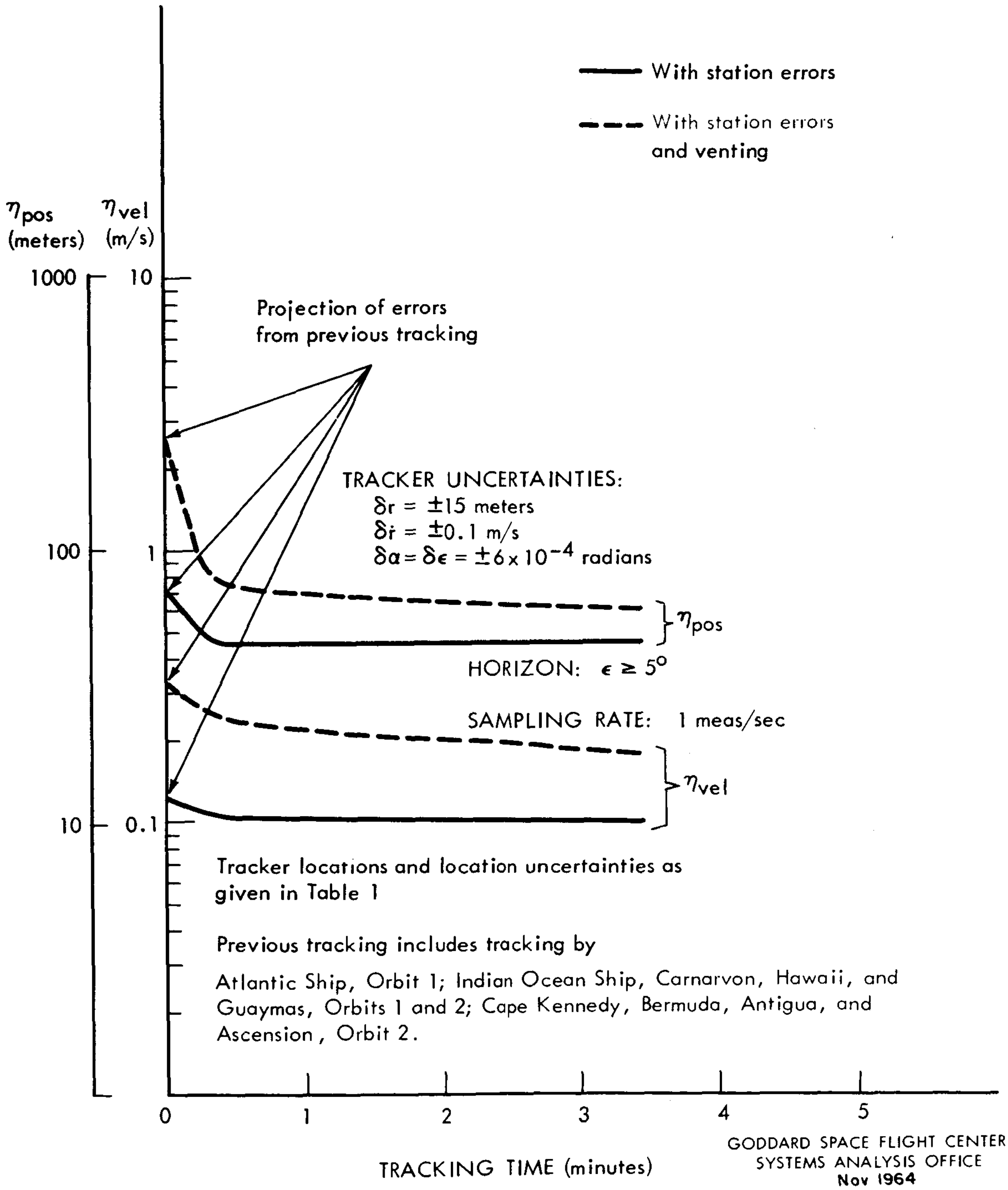

FIGURE 33

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 90°, Height 185 km
Variable Acquisition by
Cape Kennedy, Orbit 3

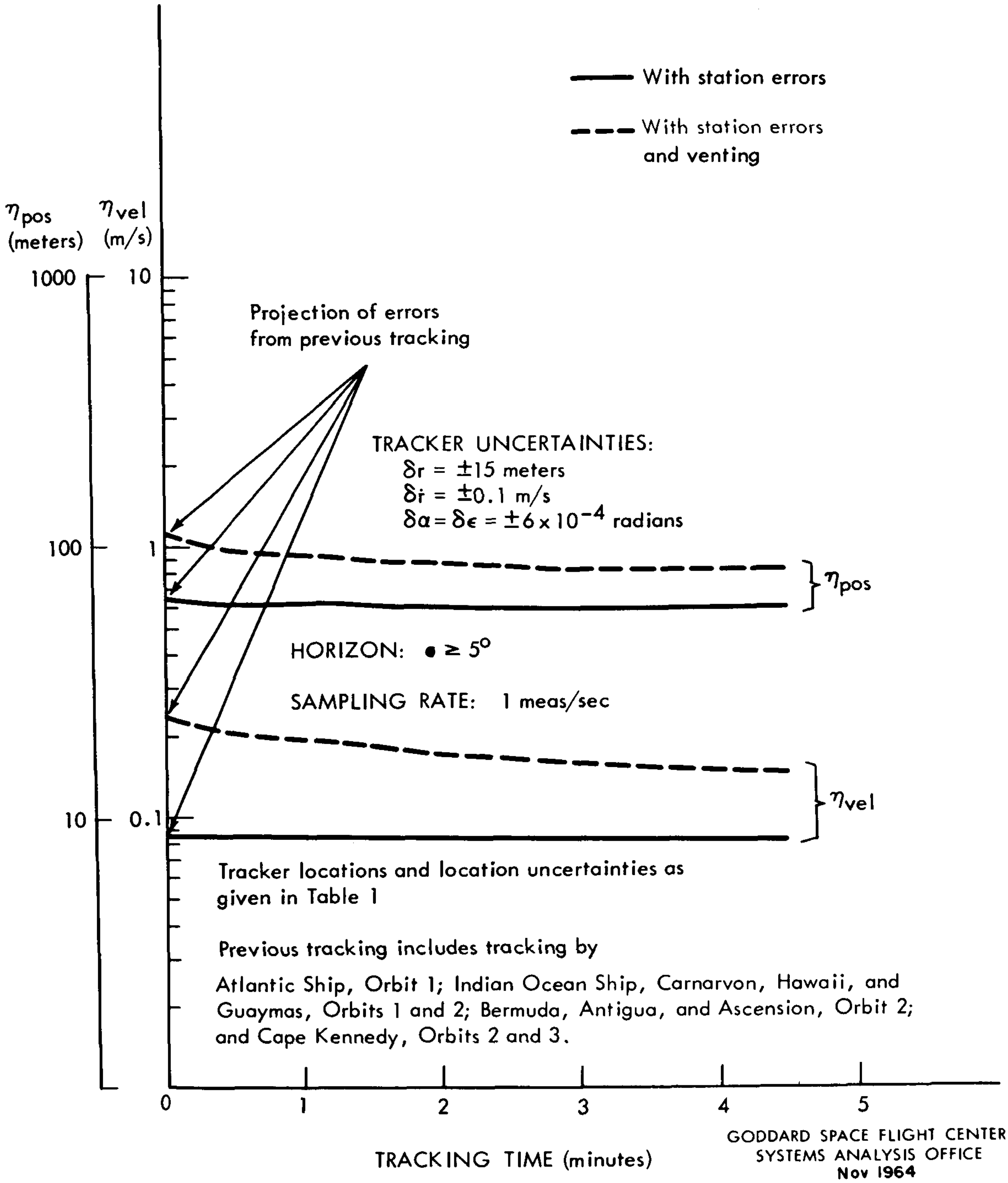

FIGURE 34

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 90°, Height 185 km
Variable Acquisition by
Antigua, Orbit 3

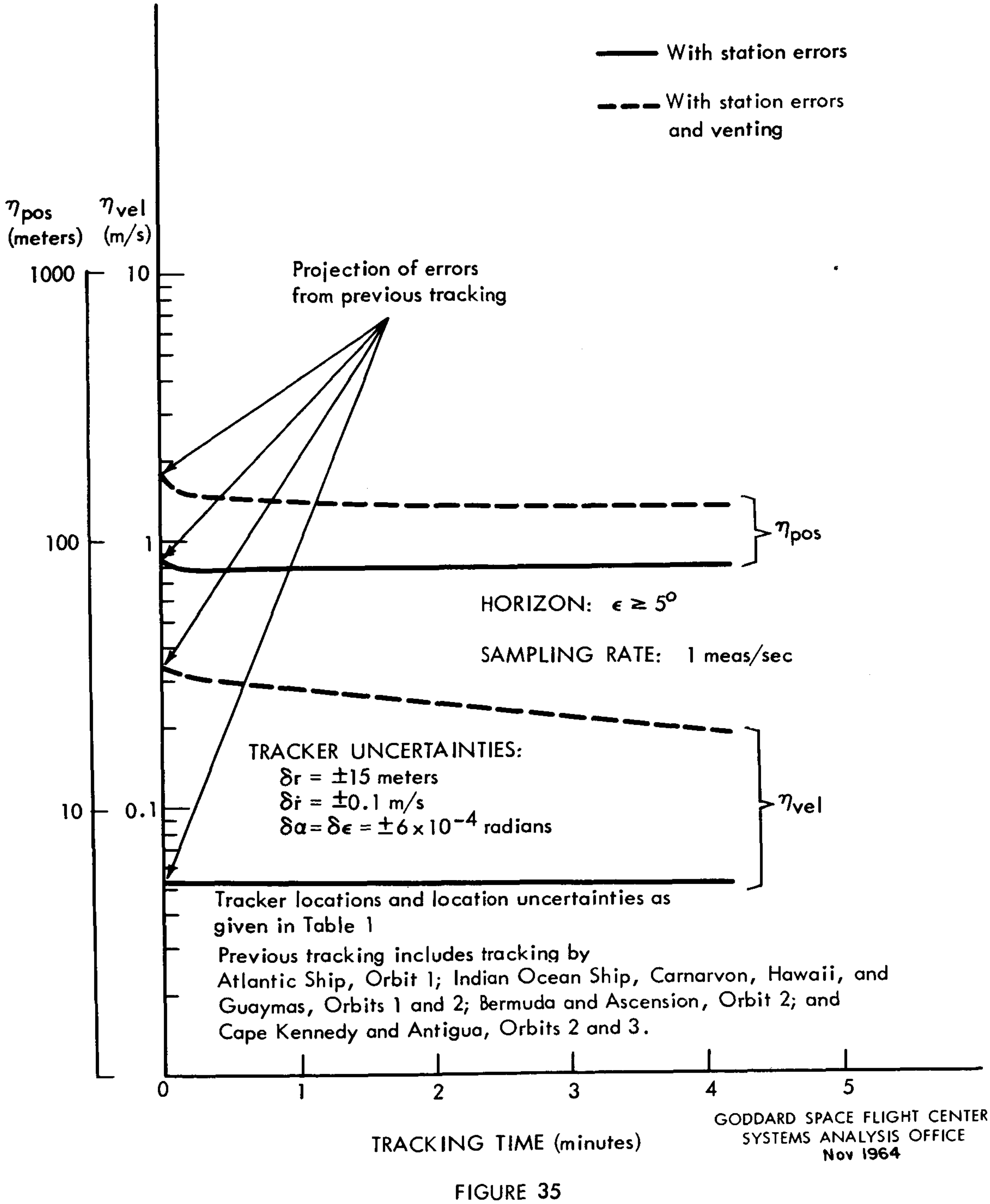

FIGURE 35

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 90°, Height 185 km
Variable Acquisition by
Ascension, Orbit 3

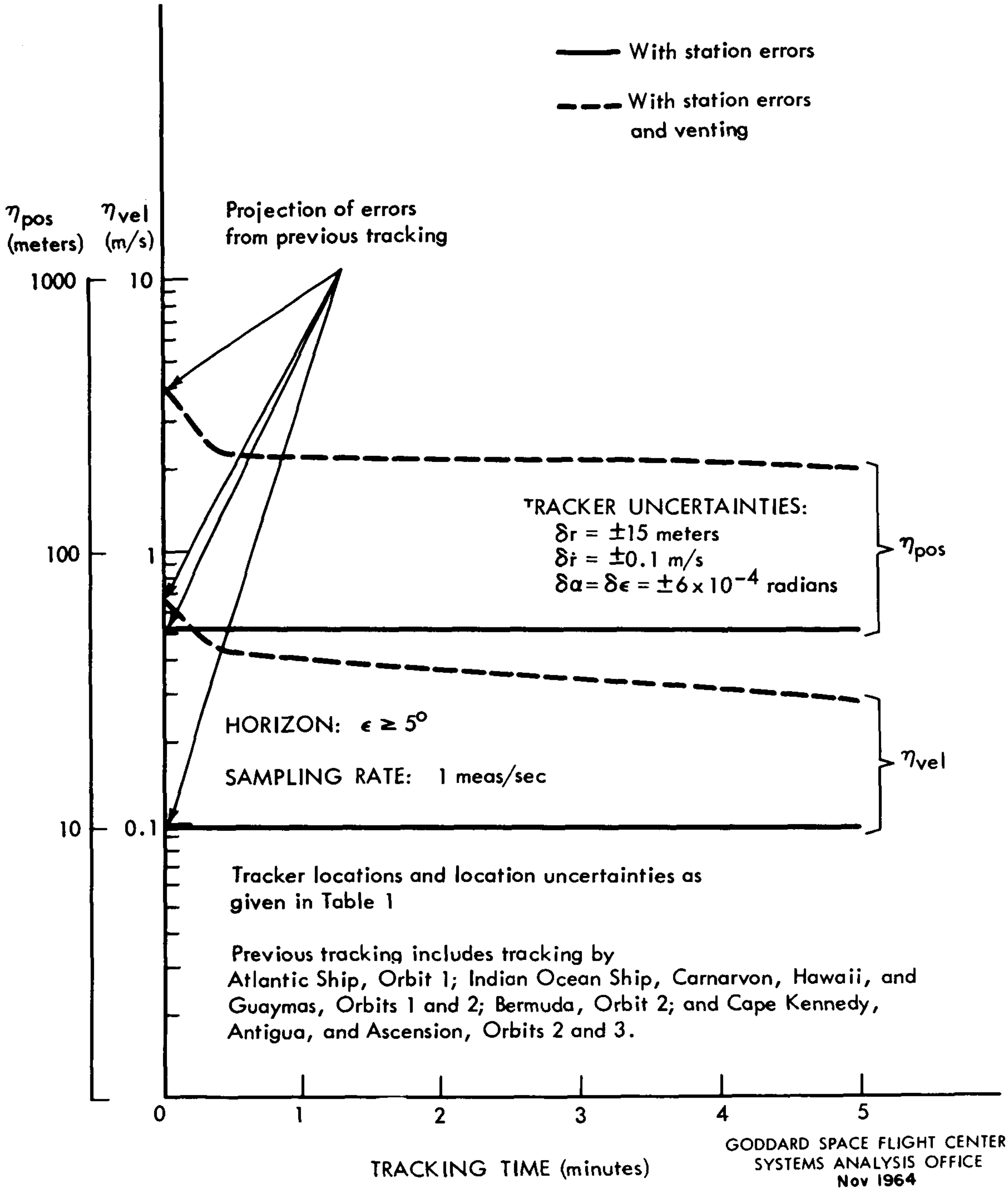

FIGURE 36

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 90°, Height 185 km
Variable Acquisition by
Indian Ocean Ship, Orbit 3

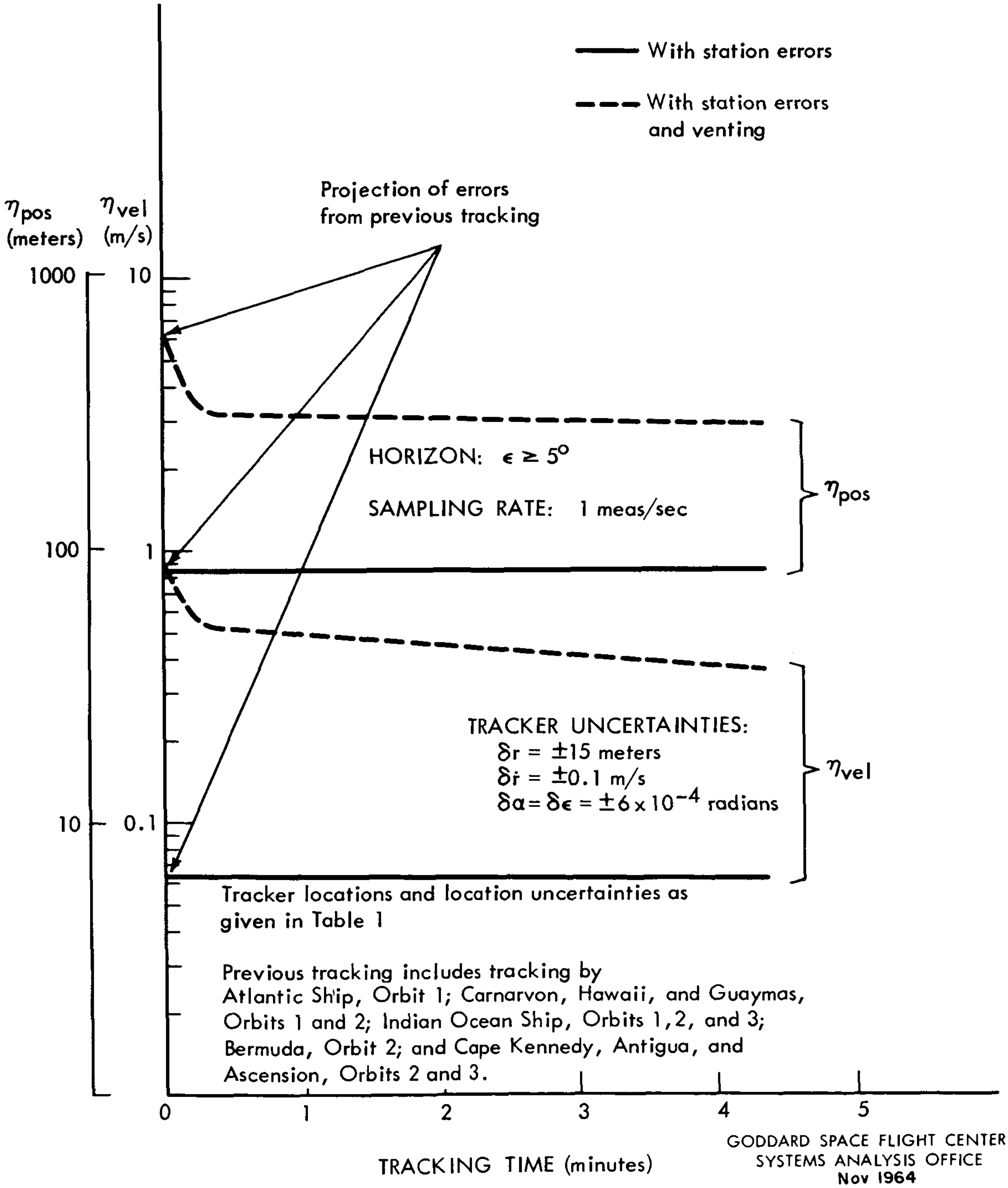

FIGURE 37

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 90°, Height 185 km
Variable Acquisition by
Guam, Orbit 3.

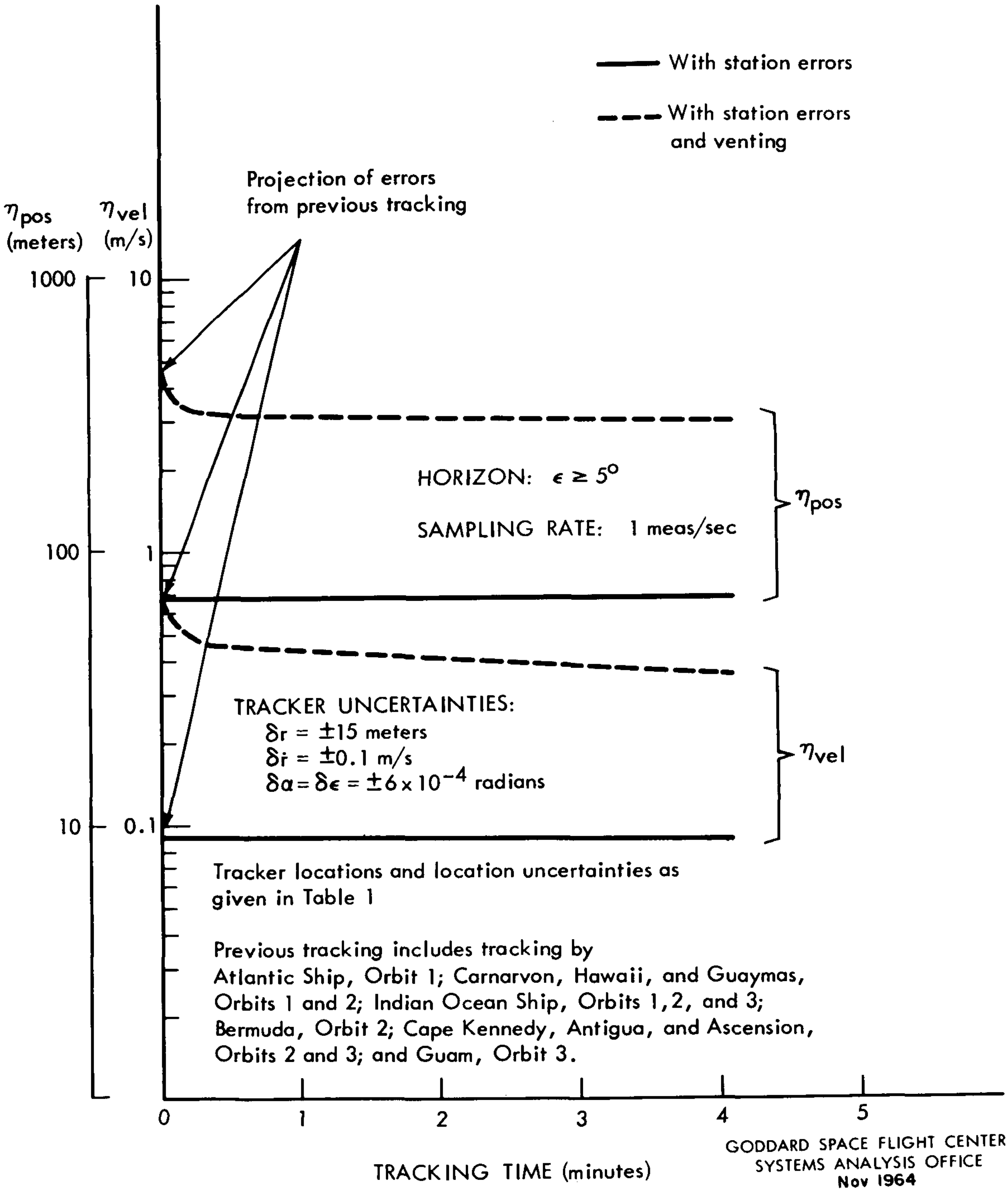

FIGURE 38

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 90°, Height 185 km
Variable Acquisition by
Hawaii, Orbit 3

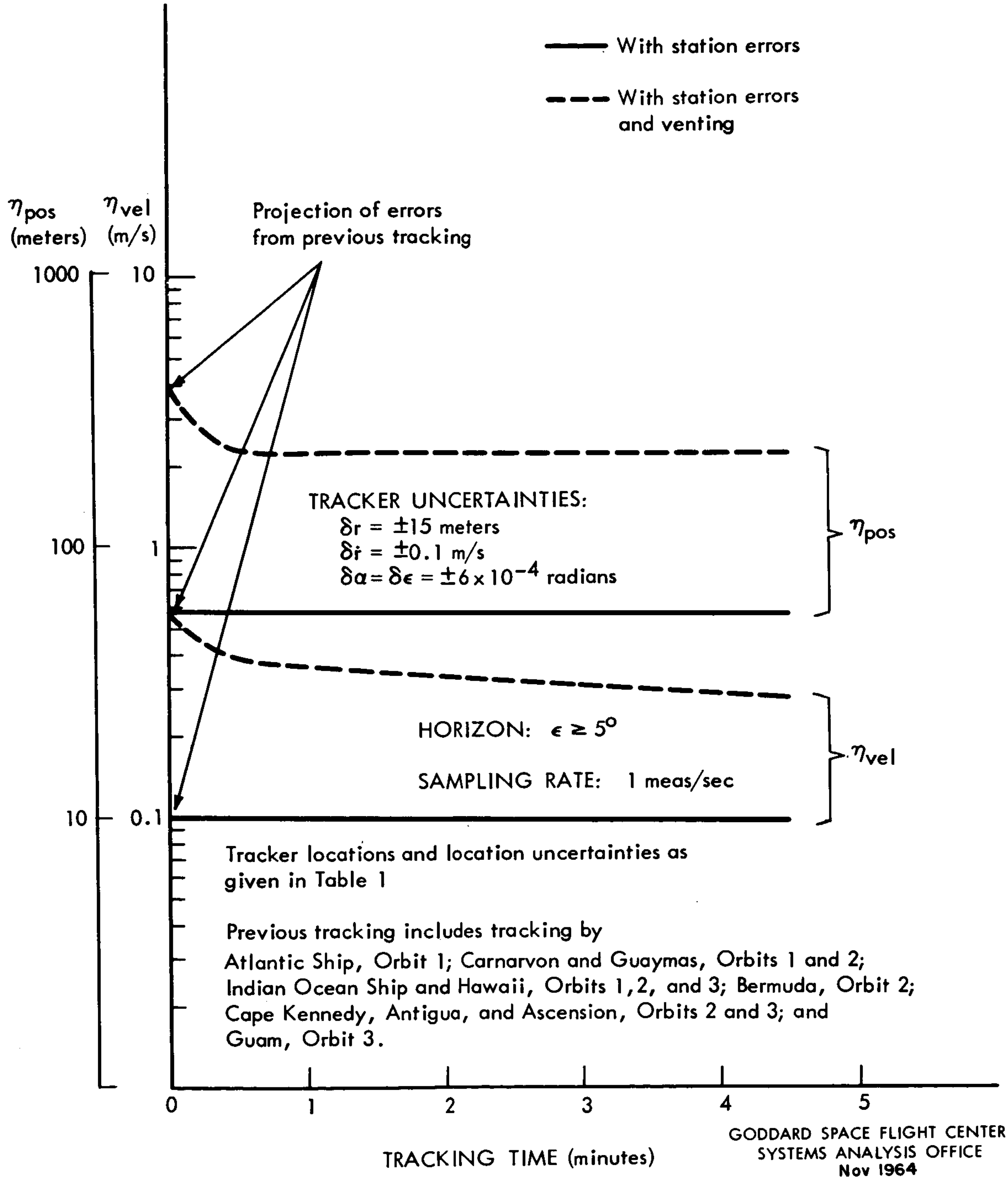

FIGURE 39

Errors in Spacecraft Position and Velocity
Apollo Parking Orbit, Launch Azimuth 90°, Height 185 km
Variable Acquisition by
Guaymas, Orbit 3

FIGURES 40-51

ERRORS IN SPACECRAFT POSITION AND VELOCITY
APOLLO PARKING ORBIT,LAUNCH AZIMUTH 108°, HEIGHT 185 KM.

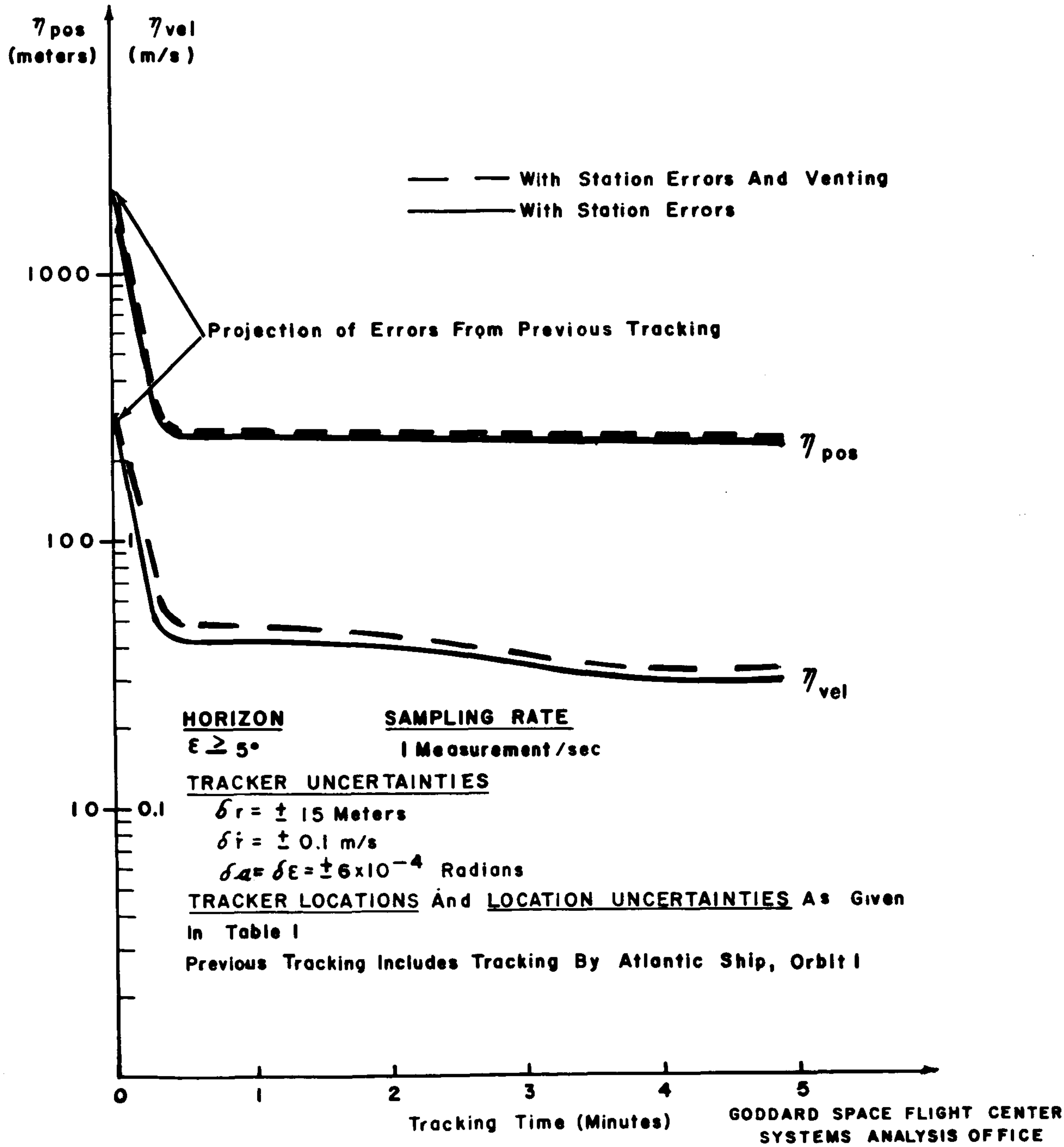

FIGURE 40

Errors in Spacecraft Position and Velocity Apollo Parking Orbit, Launch Azimuth 108° Orbit Height 185 Km. Variable Acquisition by Ascension, Orbit I

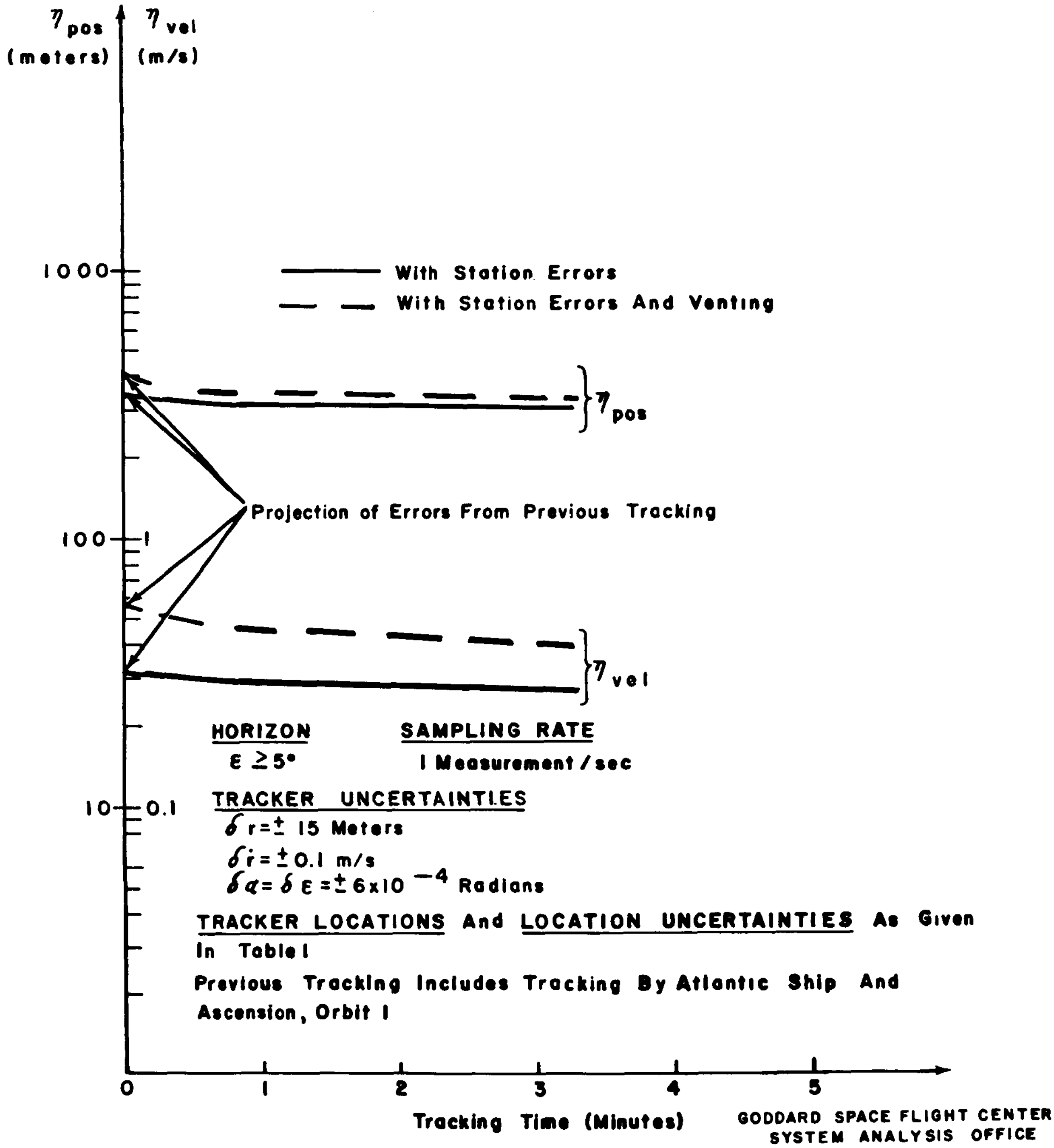

FIGURE 41

Errors in Spacecraft Position and Velocity Apollo Parking Orbit, Launch Azimuth 108° Orbit Height 185 Km. Variable Acquisition by Indian Ocean Ship, Orbit I

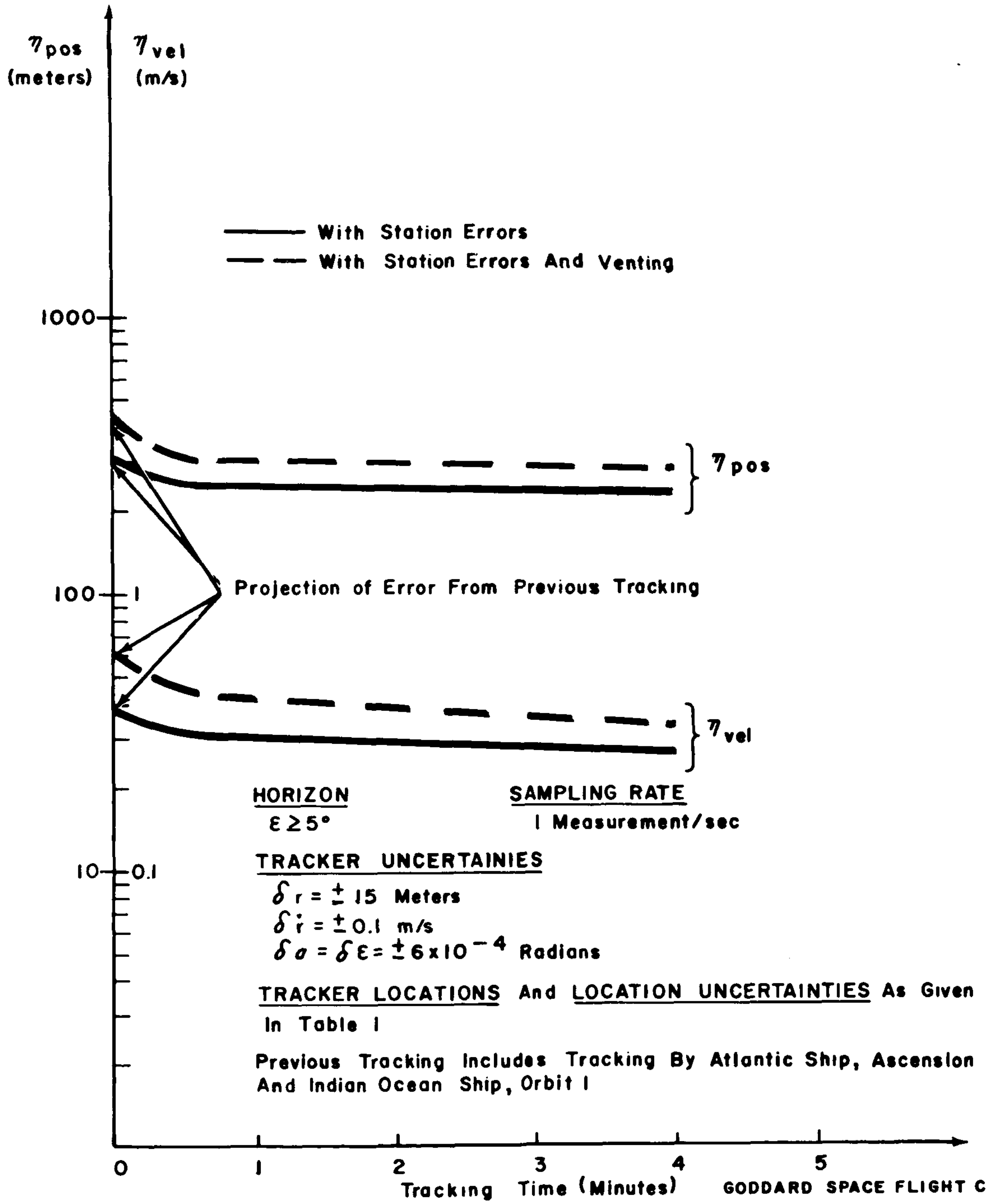

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FIGURE 42

Errors in Spacecraft Position and Velocity Apollo Parking Orbit
Launch Azimuth 108 Orbital Height 185 Km.
Variable Acquisition by Carnarvon, Orbit I

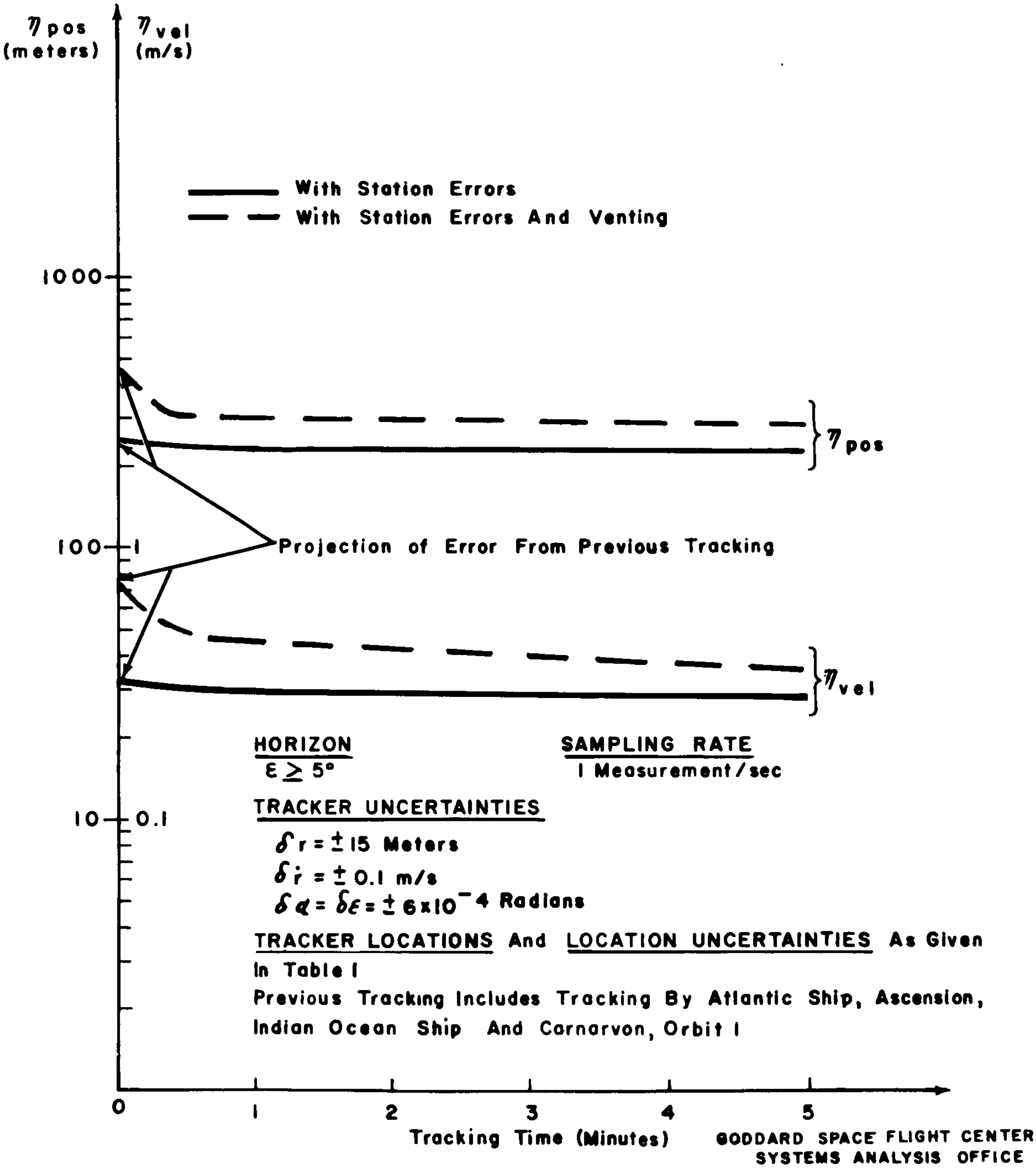

FIGURE 43

Errors in Spacecraft Position and Velocity Apollo Parking Orbit I
Launch Azimuth 108° Orbit Height 185 Km.
Variable Acquisition by Pacific Ship, Orbit I

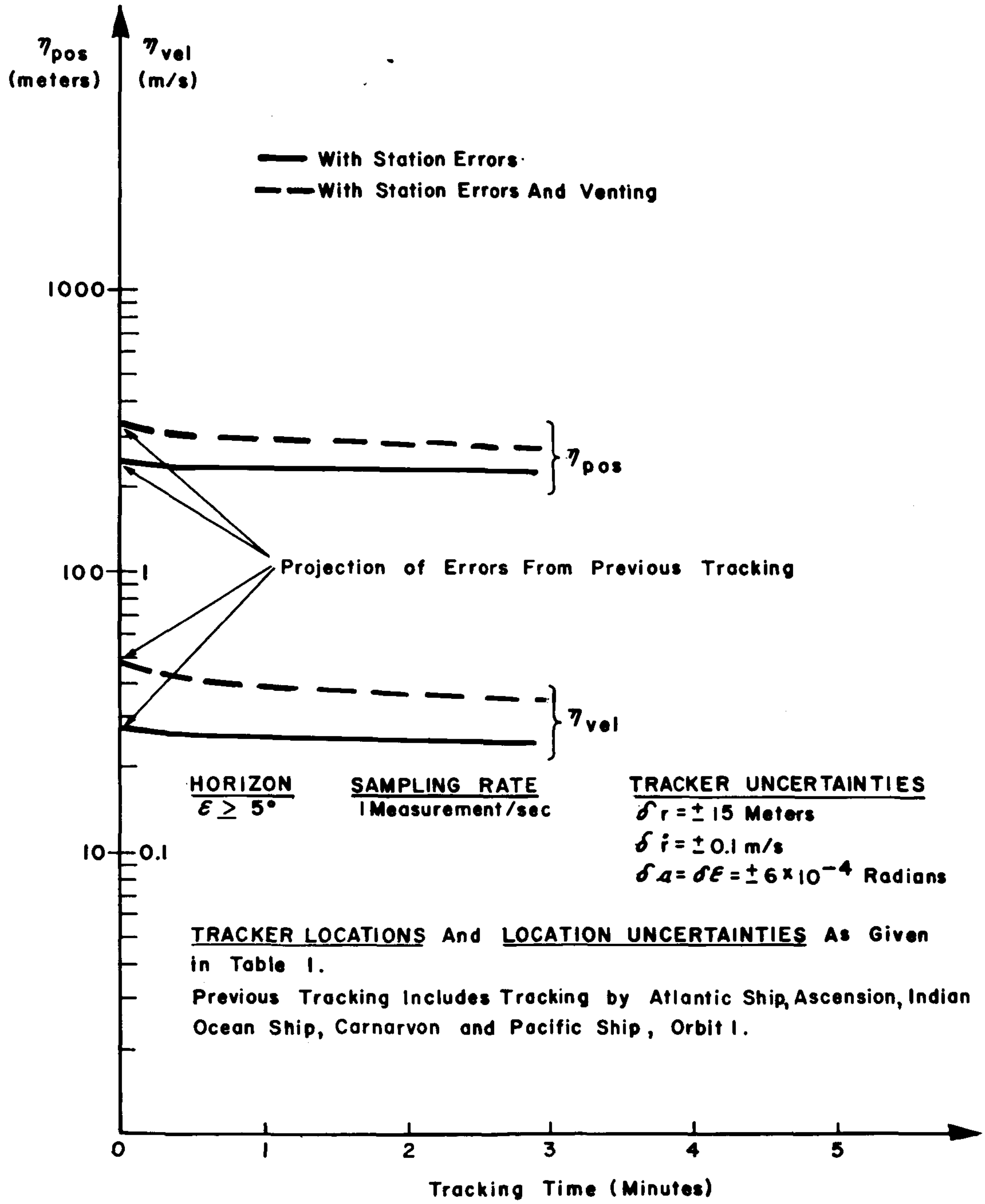

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FIGURE 44

Errors in Spacecraft Position and Velocity Apollo Parking Orbit
Launch Azimuth 108° Orbit Height 185 Km.
Variable Acquisition by Hawaii Orbit I

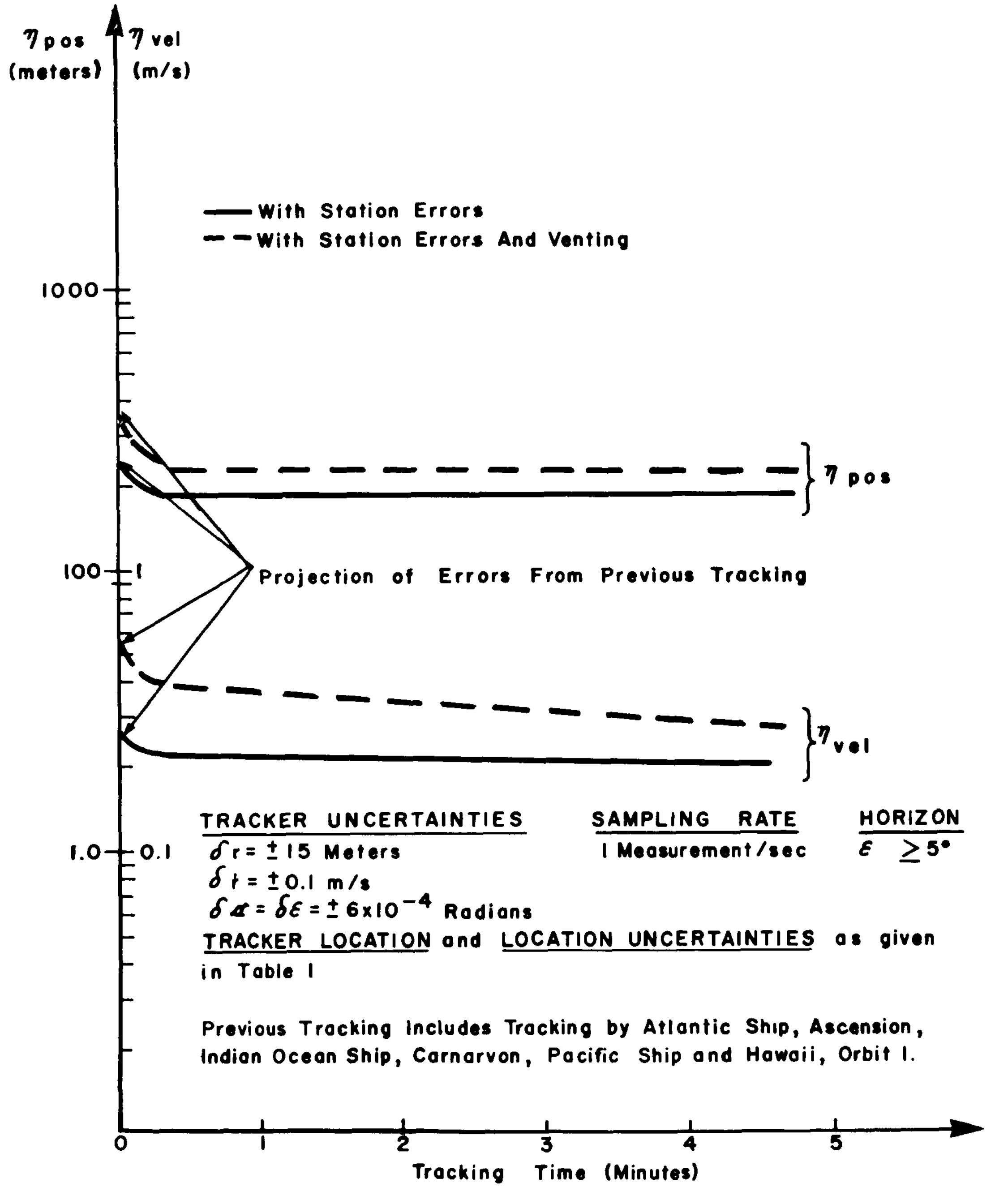

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FIGURE 45

Errors in Spacecraft Position and Velocity Apollo Parking Orbit
Launch Azimuth 108° Orbit Height 185 km
Variable Acquisition by Guaymas, Orbit I

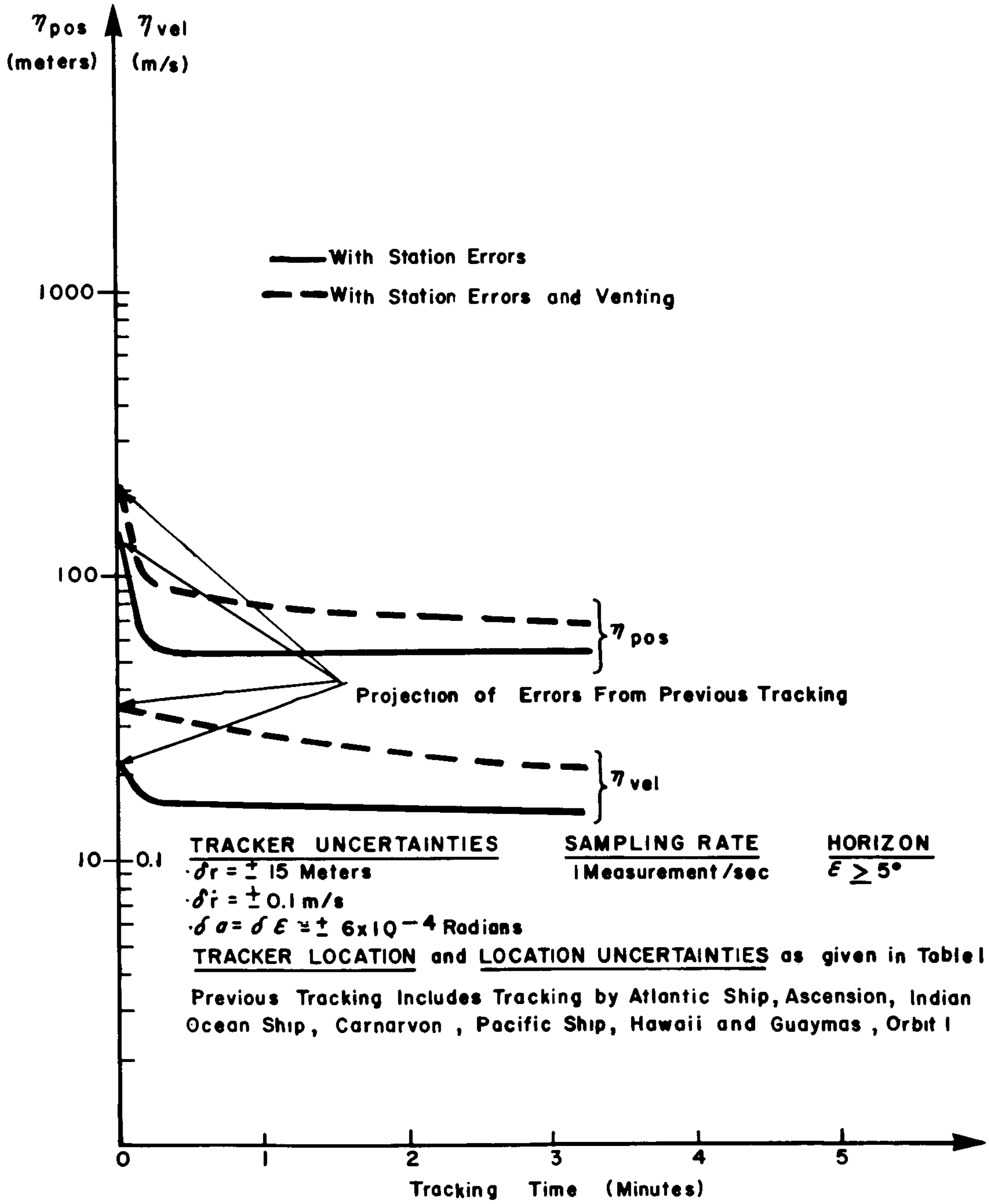

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FIGURE 46

Errors in Spacecraft Position and Velocity Apollo Parking Orbit
Launch Azimuth 108° Orbit Height 185 km
Variable Acquisition by Cape Kennedy, Orbit 2

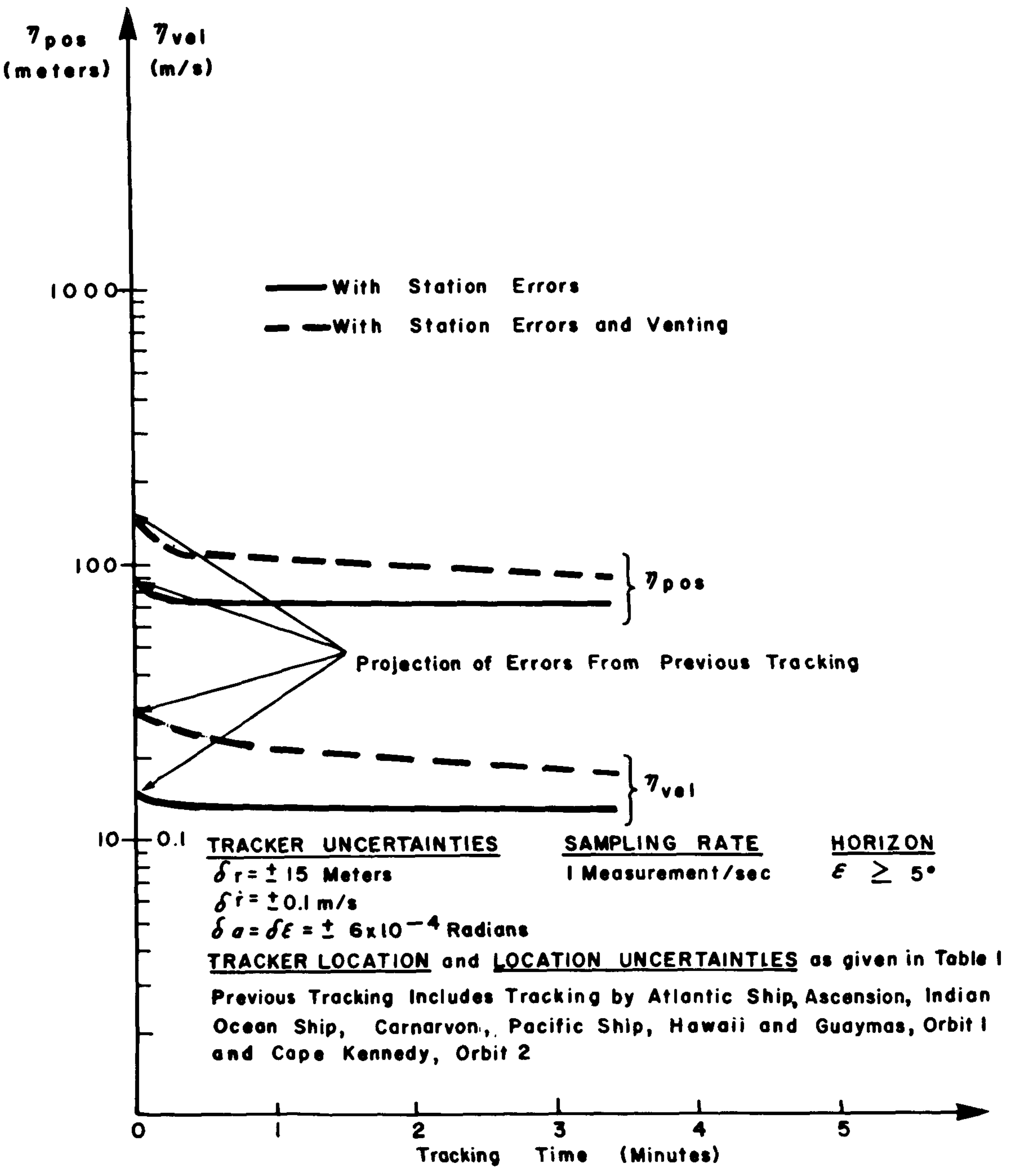

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FIGURE 47

Errors in Spacecraft Position and Velocity Apollo Parking Orbit
Launch Azimuth 108° Orbit Height 185 km.
Variable Acquisition by Antigua, Orbit 2

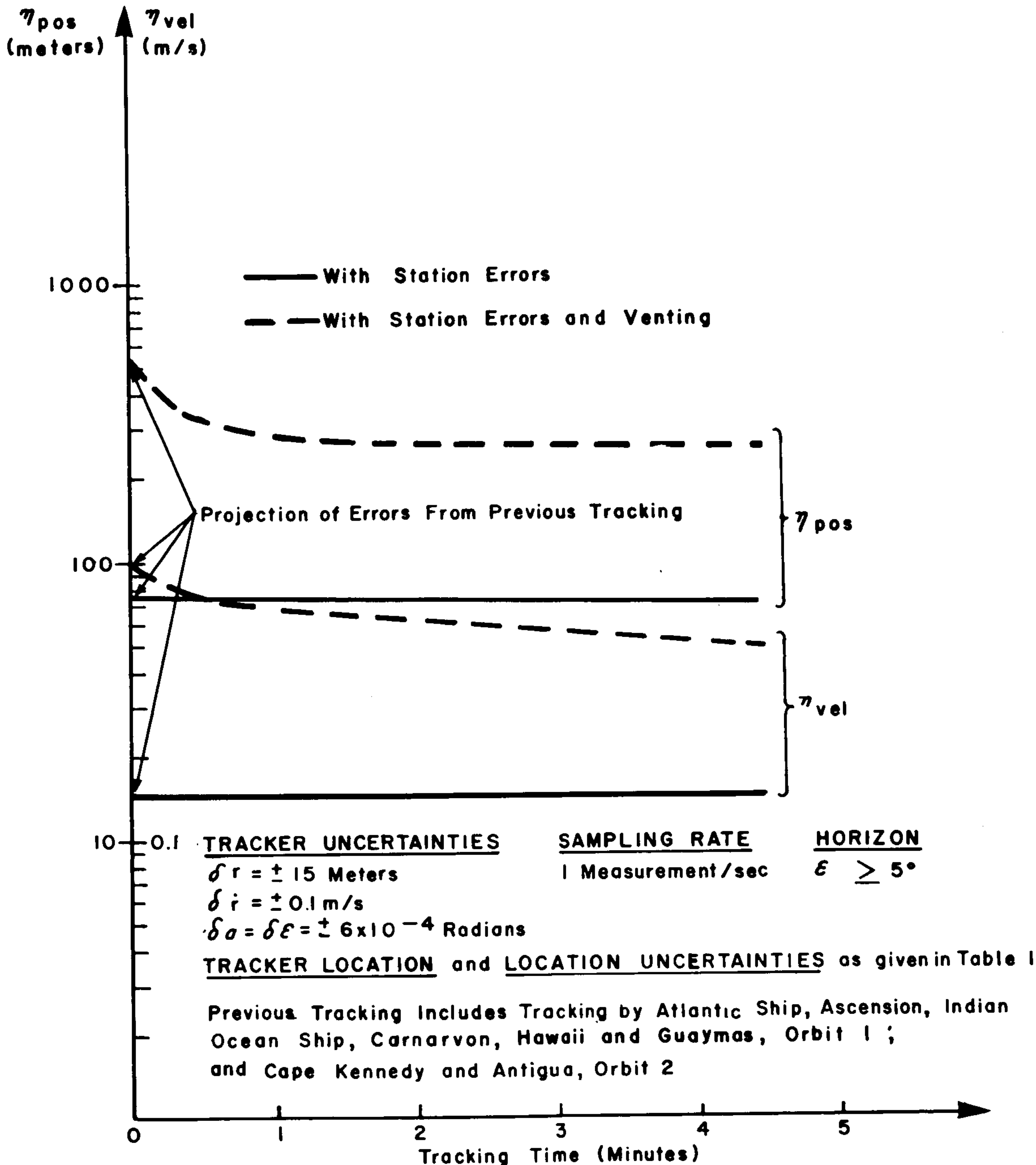

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FIGURE 48

Errors in Spacecraft Position and Velocity Apollo Parking Orbit
Launch Azimuth 108° Orbit Height 185 km.
Variable Acquisition by Indian Ocean Ship, Orbit 2

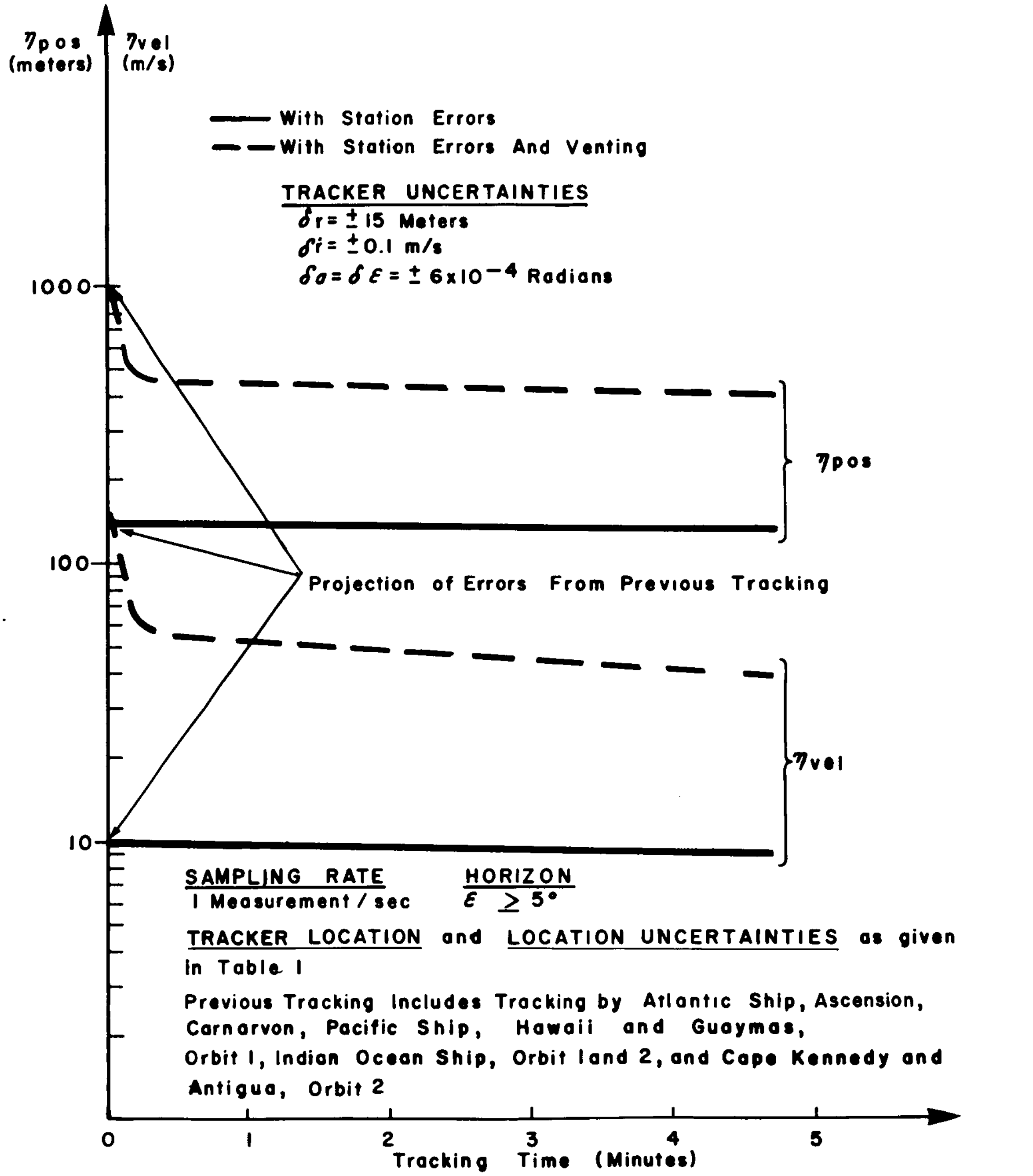

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FIGURE 49

Errors in Spacecraft Position and Velocity Apollo Parking Orbit
Launch Azimuth 108° Orbit Height 185 Km.
Variable Acquisition by Guam, Orbit 2

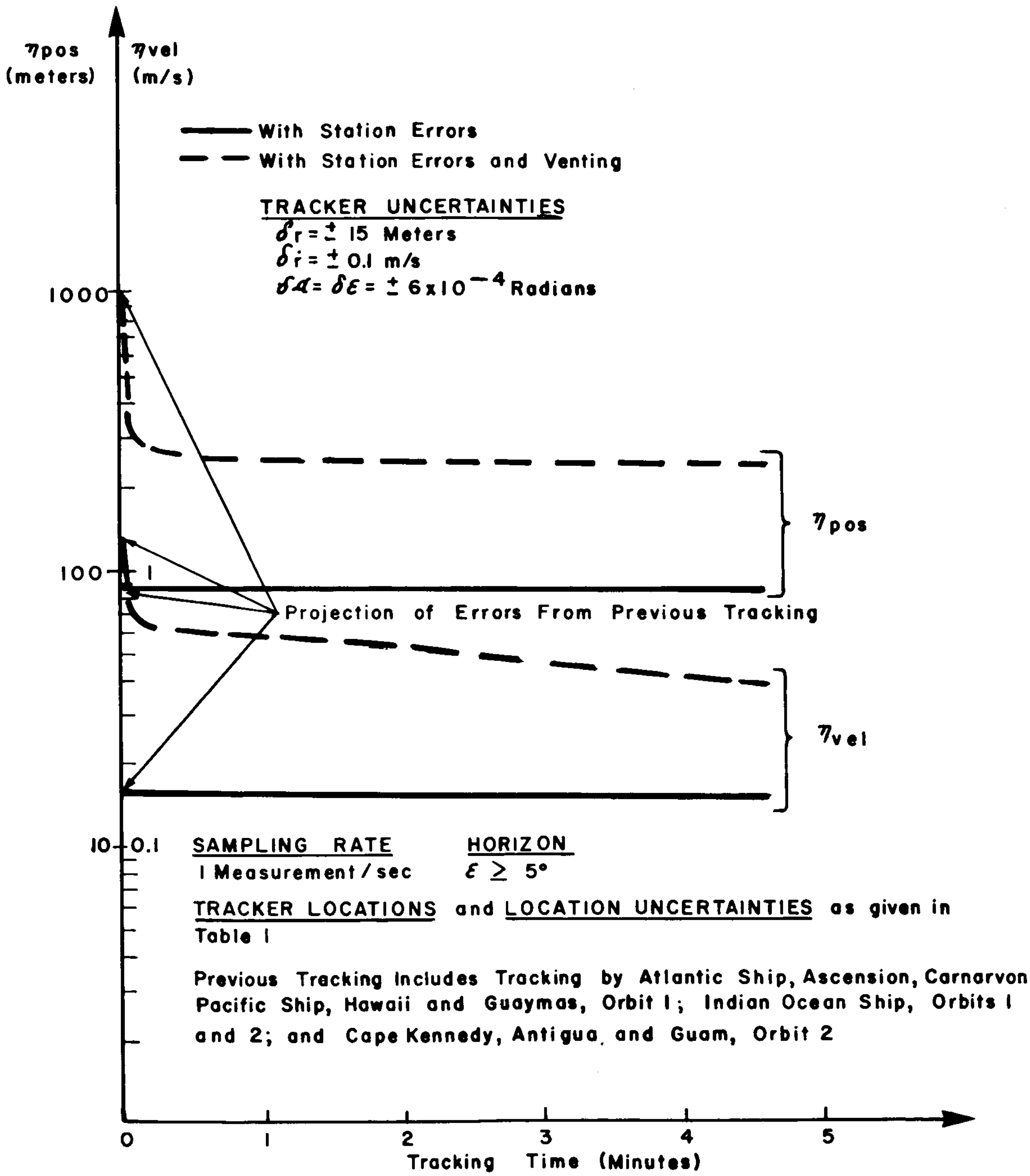

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FIGURE 50

Errors in Spacecraf Position and Velocity Apollo Parking Orbit
Launch Azimuth 108° Orbit Height 185 Km.
Variable Acquisition by Guaymas, Orbit 2

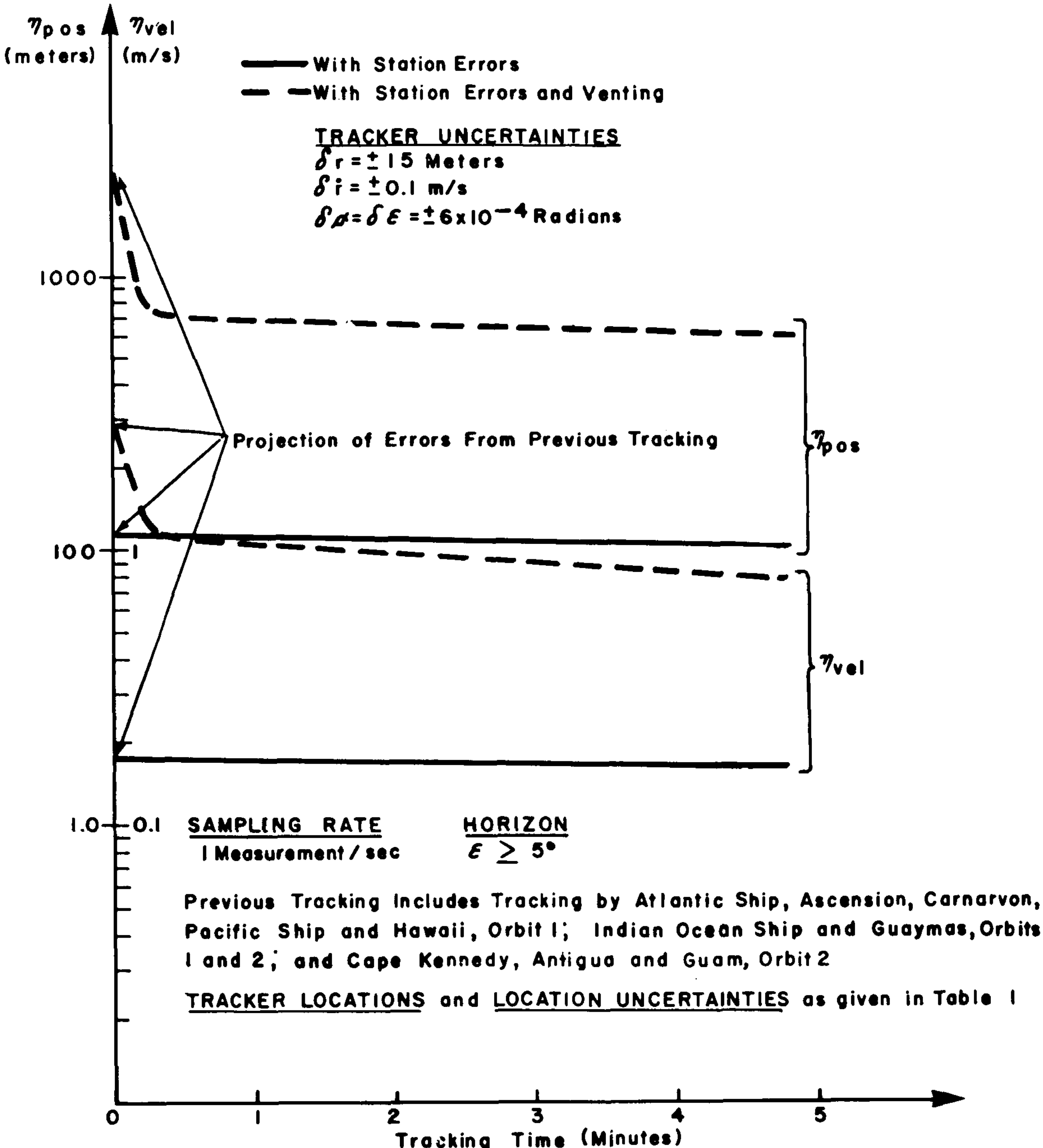

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FIGURE 51

Errors in Spacecraft Position and Velocity Apollo Parking Orbit
Launch Azimuth 108° Orbit Height 185 Km
Variable Acquisition by Indian Ocean Ship, Orbit 3